Phase 4: Project Analysis

Preliminary Project Report

Total Maximum Daily Load for Pathogens in Watsonville Sloughs, Santa Cruz County, California

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Regional Water Quality Control Board
Central Coast Region

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1. PROJECT DEFINITION

1.1. Introduction

Watsonville Slough is located in the southern portion of Santa Cruz County and is the receiving water for approximately 13,000 acres of land under a variety of land uses. Three tributaries flow into Watsonville Slough, including Harkins Slough, Hanson Slough, and Struve Slough. Galligan Slough is tributary to Harkins Slough Figure 1-1.

Watsonville Slough is listed on the California 303(d) list for non-attainment of water quality standards for pathogens. Based on historic and recent data, pathogen indicator organisms (fecal coliform and *E. coli*) occur in concentrations above Basin Plan objectives for contact recreational uses in multiple locations throughout the Slough system and throughout both wet and dry seasons.

Section 303(d) of the Clean Water Act requires the State to establish the Total Maximum Daily Load (TMDL) for pathogens at a level necessary to attain water quality standards. The State must also incorporate into the TMDL seasonal variations and a margin of safety that takes into account any lack of knowledge concerning the relationship between load limits and water quality.

1.2. Listing Basis

The Regional Board's basis for listing Watsonville Slough on the 1998 303(d) impaired waters list is not documented. However, based on analysis for bacteria by the County of Santa Cruz Environmental Health Services over the period 1977 to 2000, the waterbody is impaired. The County's data are discussed below.

1.3. Beneficial Uses

The beneficial uses for Watsonville Slough and its tributaries identified in the Basin Plan are shown in Table 1-1. Only Watsonville Slough is listed as impaired for pathogens. Nevertheless, all tributary waterbodies are included in this analysis of impairment by pathogens.

Table 1-1. Basin Plan-designated beneficial uses for waterbodies in the Watsonville Slough Watershed.

Waterbody Names	REC1	REC2	WILD	WARM	SPWN	BIOL	RARE	EST	COMM	SHELL
Watsonville Slough	X	X	X	X	X	X	X	X	X	X
Harkins Slough	X	X	X	X	X	X	X	X	X	X
Gallighan Slough	X	X	X	X	X	---	X	X	X	X
Hanson Slough	X	X	X	X	X	X	X	X	X	X
Struve Slough	X	X	X	X	X	X	X	X	X	X

Source: Regional Water Quality Control Board, Basin Plan 1994, p. II-6.

Water Contact Recreation (REC1): Uses of water for recreational activity involving body contact with water, where ingestion of water is reasonably possible.

Non-Contact Water Recreation (REC2): Uses of water for recreation activities involving proximity to water, but not normally involving bodily contact with water, where ingestion of water is reasonably possible.

Wildlife Habitat (WILD): Uses of water that support terrestrial ecosystems.

Warm Fresh Water Habitat (WARM): Uses of water that support warm water ecosystems.

Spawning, Reproduction, and/or Early Development (SPWN): Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish.

Preservation of Biological Habitats of Special Significance (BIOL): Uses of water that support designated areas of habitats, such as established refuges, parks, sanctuaries, ecological reserves, or Areas of Special Biological Significance.

Rare, Threatened, or Endangered Species (RARE): Uses of water that support habitat necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened, or endangered.

Estuarine Habitat (EST): Uses of water that support estuarine ecosystems.

Commercial and Sport Fishing (COMM): Uses of water for commercial or recreational collection of fish, shellfish, or other organisms.

Shellfish Harvesting (SHELL): Uses of water that support habitats suitable for the collection of filter feeding shellfish for human consumption, commercial, or sport purposes.

With the exception of the shellfish harvesting beneficial use, the actual or potential occurrence and attainment of these beneficial uses can be established based on current conditions and observed use of Watsonville Slough or its tributaries. For example, the water contact recreation, and commercial and sport fishing designations are evident in Harkins Slough, where during field reconnaissance staff have observed people fishing from the shore. Additionally, the known presence of myriad aquatic and terrestrial organisms attest to the occurrence of the beneficial uses for WARM, SPWN, BIOL, RARE, and EST. Estuarine aquatic habitat is limited to the reach of Watsonville Slough downstream of the Shell Road Pump Station. This reach is a tributary arm of the Pajaro River lagoon and supports water quality conditions and fish populations typical of the larger lagoon environment. Three-spine stickleback, arrow goby, and tidewater goby are resident estuarine species (SH&G, et al, 2003, p. 3-50).

Staff has found no evidence, historical or contemporary, of the shellfish harvesting beneficial use at Watsonville Slough. Commercial clamming occurred at the Pacific Ocean beaches north and south of the Pajaro River in the later part of the 19th century and early 20th century. However the historical accounts do not indicate this activity occurred outside of the high-energy beach environment suited to the clam.

Today, hydraulic modifications to the sloughs have resulted in conditions that all but rule out the possibility of viable populations of shellfish there. The Shell Road Pump Station and tide gate, installed in the early 1940s in close proximity to the mouth of the Slough, permitted cultivation of the fertile lands nearby, and eliminated tidal flushing, creating stagnant conditions upstream of the pump station (SH&G et al., 2003, Table 3-3). The lower lagoon portion of the Slough below the pump station is still subject to tidal influence throughout most of the year, while aquatic habitats upstream of the Shell Road tide gate and pump are freshwater (Ibid., p. 3-51). Seasonal closure of the Pajaro River Lagoon at the mouth of the Pajaro River occurs usually in late summer as flows diminish. The closure ends when winter storms generate enough runoff to breach the beach berm and flow to Monterey Bay. During closure Watsonville Slough Lagoon, which enters the Pajaro Lagoon from the north, is also closed to tidal circulation.

Hydraulic modifications, seasonal lagoon closure to tidal circulation, and lack of evidence of any previous presence, have lead Regional Board staff to propose de-designating Watsonville Sloughs for the SHELL beneficial use.

1.4. Water Quality Objectives

The Central Coast Region's Water Quality Control Plan (Basin Plan) contains specific water quality objectives that apply to pathogen indicator organisms (CCRWQCB, 1994, pg. III-3). These objectives are linked to specific beneficial uses and include:

Shellfish Harvesting (SHELL):
At all areas where shellfish may be harvested for human consumption, the median **total coliform** concentration throughout the water column for any 30-day period shall not exceed 70/100 ml, nor shall more than 10% of the samples collected during any 30-day period exceed 230/100 ml for a five-tube decimal dilution test or 330/100 ml when a three-tube decimal dilution test is used.

Water Contact Recreation (REC-1):
Fecal coliform concentration, based on a minimum of not less than five samples for any 30-day period, shall not exceed a log mean of 200 MPN per 100ml, nor shall more than 10% of all samples exceed 400 MPN per 100ml.

Non-Contact Water Recreation (REC-2):
Fecal coliform concentration, based on a minimum of not less than five samples for any 30-day period, shall not exceed a log mean of 2000 MPN per 100ml, nor shall more than 10% of all samples exceed 4000 MPN per 100ml.

1.5. Potential Effects of Pathogens on Beneficial Uses

Human Health (REC1, REC2, COMM)

The beneficial uses associated with human health are the principal water quality consideration with respect to pathogens. Bacterial indicator organisms, e.g., fecal coliform, are commonly used for predicting the presence of pathogenic organisms. If a predetermined concentration of indicator bacteria is detected in a sample, pathogenic organisms may also be present. Parts of the Watsonville Sloughs are used for recreational fishing. Elevated levels of fecal coliform are indication that the sloughs may be unsafe for swimming, fishing or other forms of water contact activities.

Aquatic Biota (WILD, WARM, SPWN, BIOL, RARE, EST)

Feces from pet cats and dogs that defecate near a storm drain or creek may be transported into the Watsonville Slough System and to the marine environment. Feral cats and dogs are also a direct source for pathogenic input into the sloughs. Waste from these animals may carry pathogens that cause human or marine animal health problems. Sea otter mortality *may* be linked with the pathogens found in cat waste. Researchers have found that "nearshore marine contamination through surface runoff would most likely result from transport and nearshore marine deposition of feline feces…" (Miller, et al., 2002, p. 1005).

Water quality criteria for REC1 have been shown to be protective of human health-related beneficial uses. In this assessment of Watsonville Sloughs and in water quality attainment strategies that follow from its findings, staff assumes that these criteria are also protective of aquatic biota beneficial uses.

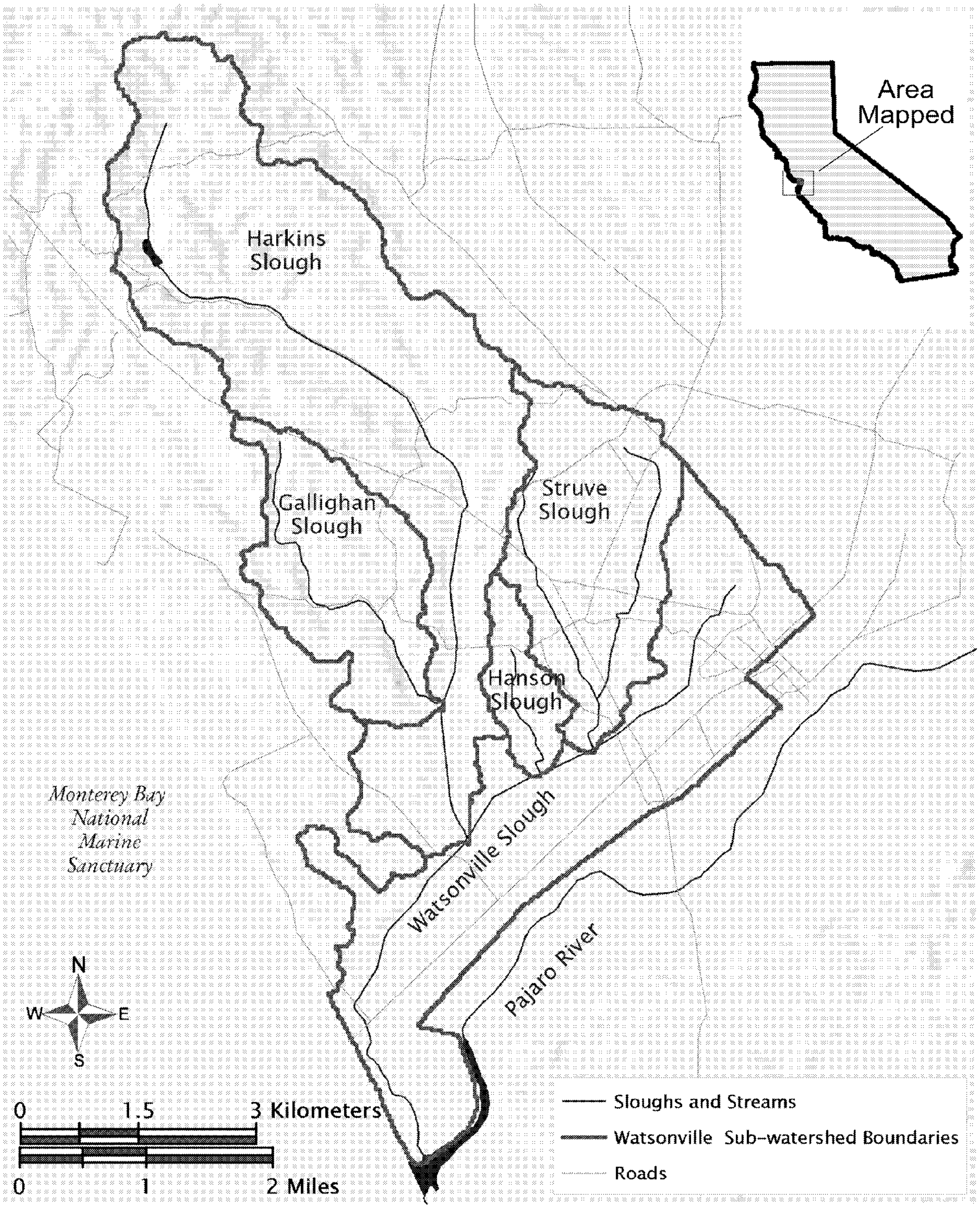


Figure 1-1: Subwatersheds of the Watsonville Sloughs
Source: Hager, et al., 2004.

2. WATERSHED DESCRIPTION

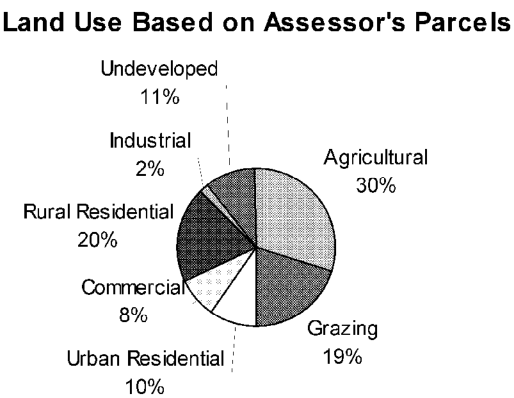
2.1. Land Use

Figure 2-1 illustrates the distribution of land use, based on county Assessor's parcel data, and land cover, based on interpreted satellite imagery. The watersheds are predominantly under agriculture and rural land uses. The following description is an excellent overview:

"California State Highway 1 roughly divides the watershed into eastern and western halves and is a major demarcation of land use. To the west, land is generally agricultural with isolated areas of industrial uses (Lee Road) and municipal landfills (Buena Vista Road). To the east, the Sloughs are generally surrounded by urban uses, denser and industrial in the south (City of Watsonville) and rural to the north (Larkin Valley). Land coverage in most areas includes marsh and riparian cover on the valley floors, and agricultural, urban, industrial and rural residential uses or undeveloped land on the hillsides. Land use encroaches into the valley floor wetlands to varying degrees leaving some areas wild and natural and others paved or completely clear of native vegetation. Channelization, diversion, filling of wetlands, damming and placement of culverts, pumps and tide gates have modified all of the streams and wetlands in the watershed from their natural state.

"Several County and City of Watsonville roads provide access and form important landmark crossings over the Sloughs. Harkins Slough Road crosses Watsonville, Struve, West Branch Struve, Hanson and Harkins Sloughs in the mid-area of the watershed. Main Street in the City of Watsonville, which is also State Highway 152, crosses Struve and Watsonville Sloughs. Beach Road occurs on the Pajaro River floodplain and connects downtown Watsonville to Sunset State Beach and the Pajaro Dunes development. Lee Road is a north-south road paralleling Highway 1, crosses Struve Slough, and connects Beach Road to Harkins Slough Road. Buena Vista Road connects the mouth of Larkin Valley to Highway 1, bisects the Gallighan Slough watershed and provides access to the municipal landfill sites before terminating at San Andreas Road at the western edge of the watershed. San Andreas Road connects Pajaro Valley and Beach Road to the terraces that bound the western edges of the lower Harkins and Gallighan Slough watersheds. Larkin Valley Road follows the path of upper Harkins Slough to the northern end of the watershed.

"The Union Pacific Railroad crosses the lower watershed from the southeast corner at Beach Road in Watsonville to the junction of San Andreas and Buena Vista Roads at the western edge of the Gallighan Slough watershed. The railroad grade is mostly on fill with bridge and culvert crossings over Watsonville, Harkins and Gallighan Sloughs." (SH&G, et al., 2003, pp. 2-1, 2-4, 2-5).



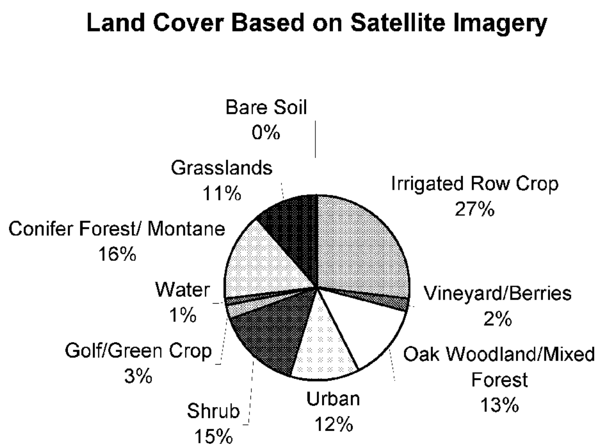


Figure 2-1 Land use and land cover by percentage of total area in Watsonville Sloughs.
Source: Land use from SH&G, et al., 2003; land cover from Hager et al., 2004.

2.2. Climate

The climate of the Watsonville Sloughs is described as Mediterranean with the moderating influence of the ocean and limited, but variable rainfall. Most of the average annual rainfall of 22.6 inches falls between December and February. SH&G, et al., report that, "year-to-year variability in rainfall is substantial, ranging between only 10.66 inches in calendar year 1976 to 48.35 in 1983. Extended periods of both drought (1976-77 and 1987-1993) and wet weather (1995-98) have occurred recently and the differences in rainfall are dramatic; for example 29.93 inches fell during the three winter months of water year 1998 (Dec., Jan., Feb.) while only 1.55 inches fell in the same months of water year 1976. The maximum daily rainfall recorded was 5.93 inches on February 14, 2000." (2003, p. 2-6).

2.3. Hydrology

Watsonville Slough is the remnant of a once more-extensive wetland and estuarine complex. The system has been historically modified to meet the needs of adjacent land uses such as agriculture and urban development. Many areas of the slough system have been channelized and filled to drain surface water. Two pump stations were also installed to enable the farming of the often-inundated lowlands and to manage flooding. The two pump stations are located at Shell Road and at the confluence of Harkins Slough. The Harkins Slough pump station is currently operated by the Pajaro Valley Water Management Agency and serves as a diversion project to deal with seawater intrusion. Additionally, there has been a history of land subsidence, which may have resulted in shallow groundwater pumping and the decomposition of underlying peat. This subsidence, in addition to road crossings with inadequately sized culverts has led to impoundments of water in these areas and reduced water circulation throughout the slough system (Hager, et al., 2004, p. 2).

Subwatersheds delineated for this study include Harkins Slough, Gallighan Slough, Struve Slough, Hanson Slough, and Watsonville Slough (Figure 1-1). A previous study by SH&G, et al., (2003) further delineated the following subwatersheds (Figure 2-2):

- Larkin Valley
- Harkins Slough Tributary
- Upper Harkins Slough
- Harkins/Watsonville Confluence
- Galligan Slough
- West Branch Struve Slough
- Struve Slough
- Upper Watsonville Slough
- Mid-Watsonville Slough
- Lower Watsonville Slough
- Lower Beach Road (lagoon)

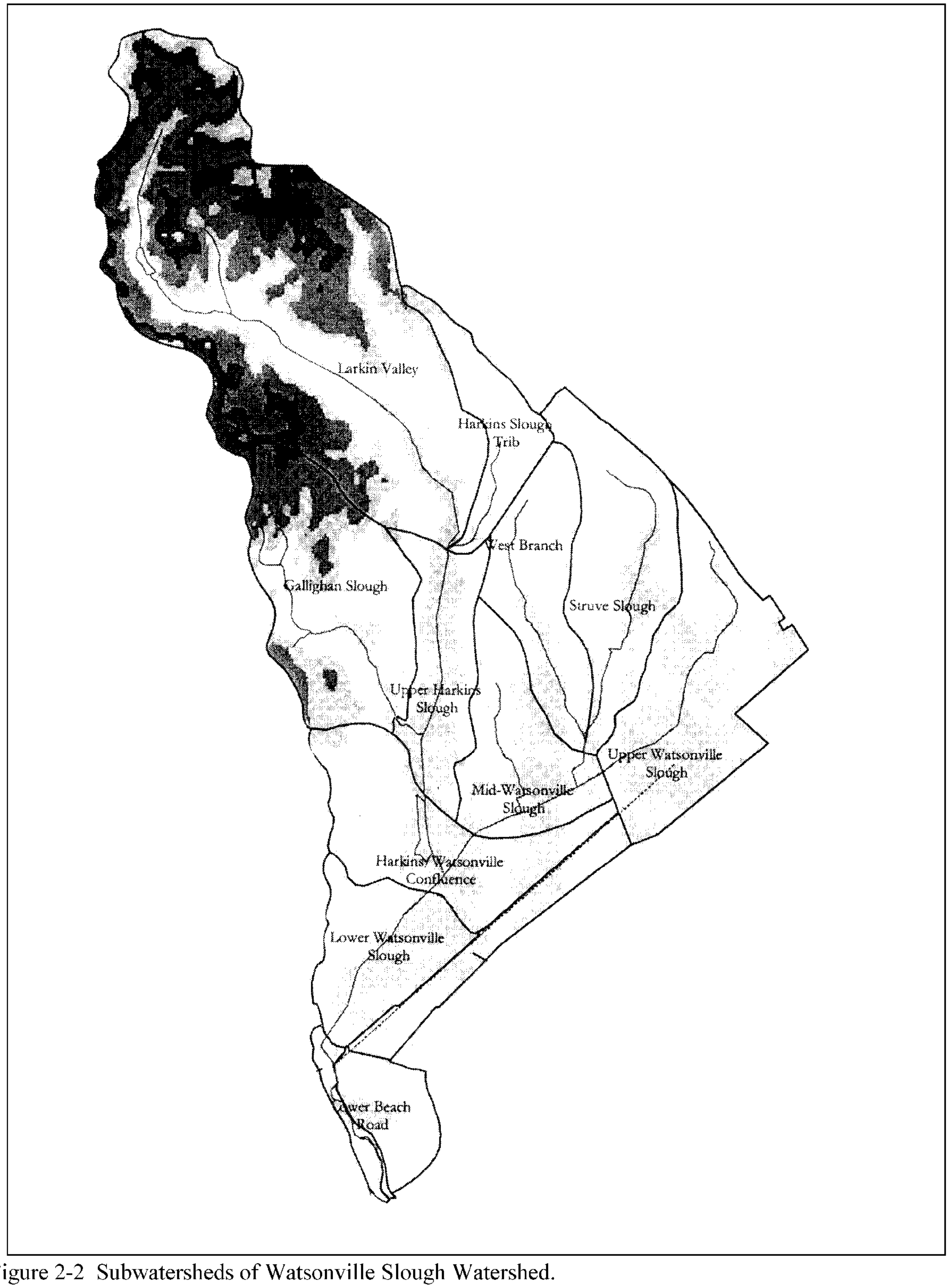


Figure 2-2 Subwatersheds of Watsonville Slough Watershed.
Source: SH&G, et al., 2003.

3. DATA ANALYSIS

3.1. Introduction

Ambient water quality assessments for pathogens rely principally on analysis for the presence of total and fecal coliform bacteria in grab samples. The total coliform group of bacteria is from the family, *Enterobacteriaceae*, which includes over 40 genera of bacteria. Bacteria of both fecal and non-fecal origin are included in the total coliform group. Common habitats for the group include soil, groundwater, surface water, the intestinal tract of animals and humans, the surface of plants, algal-mats in pristine streams, wastes from the wood industry, and biofilms within drinking water distribution systems (Hurst, et al., 2002). The total coliforms can be divided into various groups based on common characteristics. Among these, the fecal coliforms are generally indicative of fecal sources, though not all members of the group are of fecal origin (Hager, et al, 2004, p. 6). The bacteria species, *Escherichia coli*, comprises a large percentage of coliform detected in human and animal feces. Some strains of *E. coli* are pathogenic and some are not.

Analysis of water samples to detect the presence of fecal coliform and *E. coli* is one way to determine the potential presence of pathogens. However, analytical methods for quantifying bacteria lack the precision common to many other laboratory methods for water quality analysis. For example, the Multiple Tube Fermentation method results in an estimate of the most probable number (MPN) of bacteria. This number varies considerably and for a given result of say, 1,600 MPN/100ml, the 95% confidence limit ranges from 600 to 5,300 MPN/100ml. The other common method, Membrane Filtration, also has limitations, particularly with highly turbid samples. In spite of these limitations, testing for *E. coli* is one of the best available methods for indication of potential fecal contamination (Ibid., p. 7). Combined with genetic methods of microbial source tracking, strong indications of the magnitude of impairment and of the animal source of *E. coli* can be ascertained.

Because of the inherent diversity and complexity of coliform bacteria, this approach to using them as "indicator organisms" comes with a variety of problems (discussed more fully in Appendix A). An important characteristic of these bacteria to bear in mind when following this approach is the many adaptations allowing them to persist through variable and harsh environmental conditions. The "combined effects of these survival mechanisms may enable in situ aquatic growth of coliform bacteria. Therefore, a problem of elevated coliform levels for a given waterbody may not solely be addressed by bacteria sources, but rather also by controlling the conditions that promote growth." (Hager, et al, 2004, p. 8).

3.2. Data and Information Evaluated

This report relies heavily on a study conducted for the Regional Board by Julie Hager and Fred Watson, PhD of the Watershed Institute, California State University Monterey Bay. Their report, Watsonville Sloughs Pathogen Problems & Sources (Hager, et al., 2004), served to integrate existing data with data collected specifically for development of a TMDL. Appendix A includes the Hager and Watson Report sans appendices. Staff also relied on the Watsonville Sloughs Watershed Resource Conservation & Enhancement Plan prepared for the County of Santa Cruz Planning Department by a team of consultants under the direction of Swanson Hydrology & Geomorphology (SH&G, et al., 2003).

This TMDL report evaluates pathogen data available from previous assessments, as well as data gathered specifically for development of a TMDL for pathogens. The data gathered specifically for this report includes both fecal and *E. coli* data from analysis of grab samples, and the results of genetic analysis for source identification.

Existing Pathogen Data

While a number of studies have been completed in the area, most lack quantitative information on the extent, severity, and origins of pathogens in Watsonville Sloughs. Hager and Watson reviewed available reports and data on the subject, as did Regional Board staff. The studies reviewed included:

- *Pajaro River Watershed Water Quality Management Plan* (Applied Science and Engineering Inc., 1999)
- *Patterns of aquatic toxicity in an agriculturally dominated coastal watershed in California* (Hunt et al., 1999)
- *Water Resources Management Plan for Watsonville Slough System Santa Cruz County* (Questa Engineering Corporation, 1995)
- *State Mussel Watch Program* (State Water Resources Control Board, 1977-2000)
- *Toxic Substances Monitoring Program* (State Water Resources Control Board, 1977-2000)

Additional water quality monitoring has been conducted in the Watsonville Sloughs system by the organizations below. Table 3-1 summarizes the type of data and number of sites sampled in these previous studies.

- Santa Cruz County Environmental Health
- Santa Cruz County Public Works
- City of Watsonville
- Central Coast Regional Water Quality Control Board
- Pajaro Valley Water Management Agency
- University of Santa Cruz - Marc Los Huertos
- Watershed Institute (1995-1997) - John Oliver
- Santa Cruz County Resource Conservation District
- Coastal Watershed Council
- California Department of Fish and Game

Table 3-1 Summary of Previous Water Quality Studies for Watsonville Sloughs

Project Agency		**No. of Sites in Watsonville Sloughs**	**Fecal Coliform**	***E. Coli***	**TSS**	**Turbidity**	**pH, cond/salinity temperature**	**DO**	**Nutrients**	**Pesticides**	**Metals**	**Oil & Grease**	**Water Depth**	**Chloride**
Swanson Hydrology and Geomorphology, et al (2003)*	YSI data loggers	4					X	X					X	
	Water depth	5											X	
	Vertical profiles	3 (Above & below each site)					X (no pH)	X	X				X	
Hunt et al. (1999)		4								X				
Questa Engineering Corporation (1995)		10				X	X			X	X	X		
State Mussel Watch (1982 - 1993)		5								X	X			
Toxic Substance Monitoring Program (1980-1992)		7								X	X			
Santa Cruz County Environmental Health		22	**X (16 sites)**	**X (1 site)**	X (4 sites)	X (8 sites)	X	X	X	X	X			X
Santa Cruz County Public Works, Buena Vista Landfill NPDES monitoring (1992 to 2002)		4			X		X					X		X
City of Watsonville (1996 to 1998)		6			X	X	X	X	X					X
Watershed Institute-John Oliver (1995-1997)		3				X	X	X	X					
CCRWQCB – Metals, Oil & Grease, Pesticide Study (2002)		11								X	X	X		
PVWMA (1994-present)	Diversion Project NPDES monitoring	5	**X (4 sites)**		X	X	X	X	X	X (2 sites)	X (2 sites)	X (1 site)	X (3 sites)	
	Other	5			X	X	X		X					X
Central Monterey Bay Wetlands Project – Coastal Watershed Council and Santa Cruz & Monterey County Resource Conservation Districts (July 2000 –June 2001)		10				X	X	X	X					
UCSC – Marc Los Huertos et al. (October 2000 – September 2001)		2					X	X	X					

Bold text highlights data that pertain to pathogens

Source: Hager, et al., 2004, p. 10, Table 5.1.

Bacteria Data Collected for TMDL Development

Researchers designed and implemented a plan for sampling and analyzing water column grab samples to develop this TMDL for pathogens in Watsonville Slough. The plan included wet and dry season sampling for bacteria counts as well as genetic analysis of bacteria to determine their animal host.

Wet and Dry Season Sampling

The goal of the first stage of the monitoring plan was to investigate fecal bacteria levels and to confirm the existence of a potential pathogen problem in the Watsonville Slough system. This involved two monitoring campaigns at 13 sites throughout the watershed for total coliform, fecal coliform, and *E. coli*. Each monitoring campaign consisted of five synoptic sampling runs within a 30-day period. The protocols for sample collection and analysis of pathogens are detailed in the quality assurance plan for the project (Hager and Watson 2003). The results of this first stage of monitoring, confirmed that the Watsonville Slough system was in exceedance of the Basin Plan objective for fecal coliform, therefore a preliminary source analysis was needed in order to proceed with TMDL development.

Sampling Locations

The 13 primary sites that were monitored for this project are listed in Table 3-2. The location of these sites is shown in Figure 3-1. Additional sites, sampled less frequently throughout the assessment, are listed in Table 3-3.

Table 3-2 Primary monitoring sites for data collected for TMDL development.

Site Code	Site Description
WAT-PAJ	Watsonville Slough mouth at Pajaro Dunes Colony
WAT-SHE	Watsonville Slough at Shell Road pump station
WAT-AND	Watsonville Slough at San Andreas Road bridge
WAT-LEE	Watsonville Slough at Lee Road bridge
WAT-HAR	Watsonville Slough at Harkins Slough Road crossing
HAR-CON	Harkins Slough confluence with Watsonville Slough (pump station)
HAR-HAR	Harkins Slough at Harkins Slough Road crossing
HAR-RAN	Harkins Slough upstream of Ranport Road crossing
GAL-BUE	Gallighan Slough at Buena Vista Road (near landfill exit)
HAN-HAR	Hanson Slough at Harkins Slough Road crossing
STR-LEE	Struve Slough at Lee Road crossing
STR-HAR	Struve Slough at Harkins Slough Road crossing
STR-CHE	Struve Slough at Cherry Blossom Drive

Source: Hager, et al., 2004, p. 20.

Table 3-3 Secondary monitoring sites for data collected for TMDL development.

Site Code	Site Description
HAR-H1U	Harkins Slough just upstream of Hwy 1 crossing
HAR-BUE	Harkins Slough at Buena Vista Road
HAR-PEA	Harkins Slough at Peaceful Oaks Lane
HAR-916	Harkins Slough upstream of HAR-PEA
STR-CH1	Struve Slough upstream of STR-CHE
STR-CH2	Struve Slough upstream of STR-CH1
STR-CH3	Struve Slough upstream of STR-CH2
STR-CH4	Struve Slough downstream of STR-CHE
STR-CH5	Struve Slough downstream of STR-CH4
STR-TRB	Small tributary to Struve Slough located just upstream of STR-CHE
STR-PIP	Pipe near STR-CHE
STR-AIR	Struve Slough at Airport Blvd.

Source: Hager, et al., 2004, p. 20.

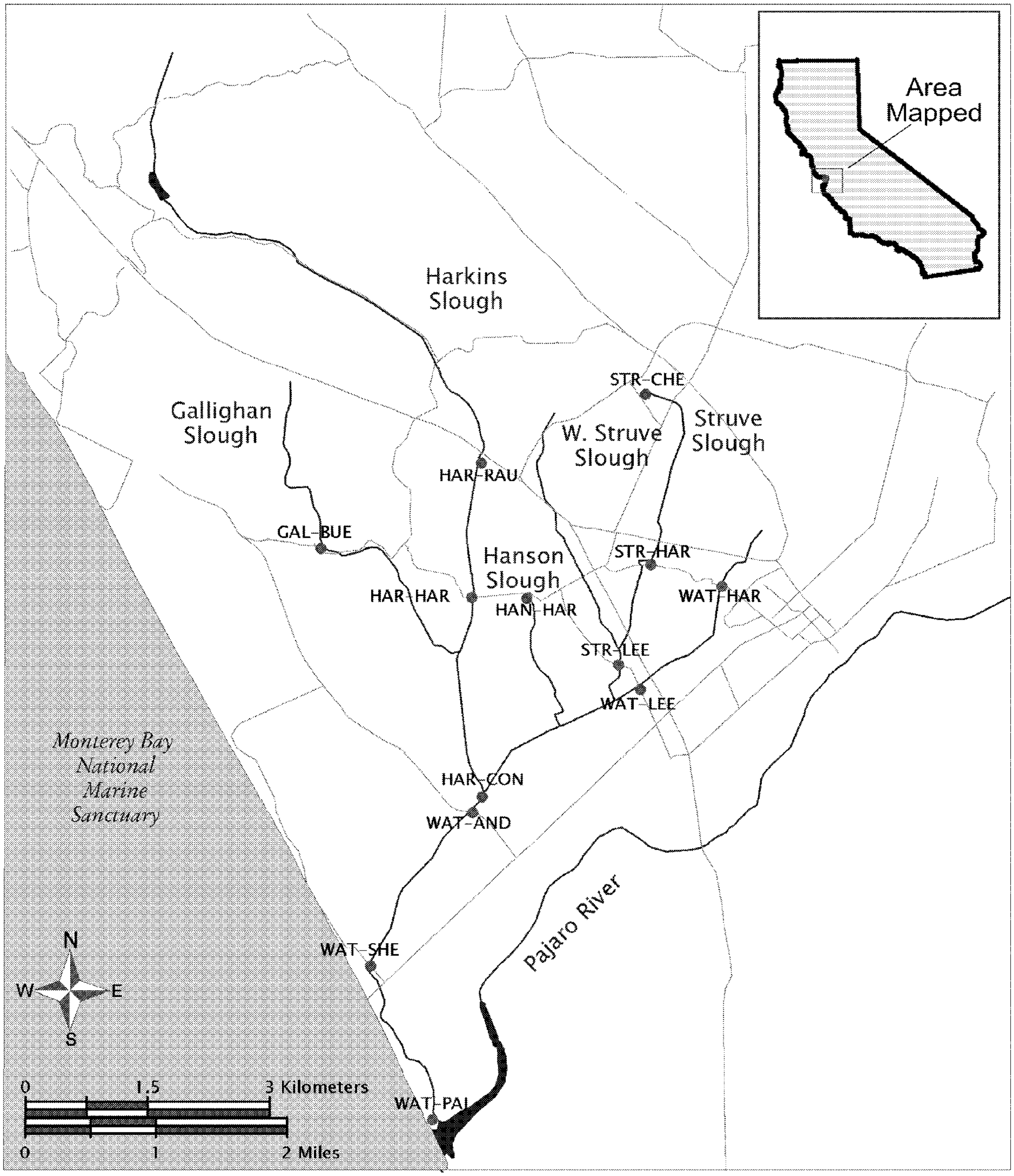


Figure 3-1 Location of sampling stations for Hager, et al., (2004) filed sampling. See Table 3-2 for Site Code descriptions. Source: Hager, et al., 2004, Figure 5.1.

Genetic Testing

The second stage of the assessment was a preliminary source analysis of coliform bacteria based on genetic analysis of samples from three sites that were identified as "hot spots" for fecal contamination. These same sites are also representative of dominant land uses throughout the watershed. The laboratory group led by Dr. Betty Olson at the Department of Environmental Analysis and Design at the University of California, Irvine analyzed a total of 16 samples using the Toxin Gene Biomarker method. This method uses polymerase chain reaction (PCR) to identify toxin biomarker genes in *E. coli* (Ibid., p. 18).

Hagar, et al. determined the Toxin Gene Biomarker method to be most appropriate for this study by comparing it to other methods of genetic source identification of bacteria, and taking into account budgetary constraints. The Toxin Gene Biomarker screens a large proportion of the entire *E. coli* population of a single water sample and the biomarkers have proved to be geographically stable. The major limitation of this method is that only a limited number of toxin genes have been identified thus far. The biomarkers used in this study included those for human, cow, bird, rabbit, and dog. Sources other than these were not identified in the analysis conducted for this project (Ibid.). The full text of the report prepared by the Olson lab describes the methodology in greater detail (Appendix B).

Hydrologic Data

SH&G, et al. (2003) conducted visual assessments of water circulation within each reach from December 2000 to June 2001. Water circulation was inspected through observation of flow velocity, signs of stagnation (floating debris, flotsam), baseflow and storm response. They also conducted field surveys of hydraulic control structures from winter flood through spring recession in order to assess these structures' influence on circulation. Most of the structures, constructed in early to mid-1900s, are associated with road crossings and drainage control and may cause backwater conditions during flooding and reduce hydraulic capacity. SH&G, et al. rated each structure for its condition, the degree of flow constriction, whether it was clogged or inoperable, and whether the structure appeared adequately sized. Using these field surveys and historical aerial photographs, SH&G, et al. classified the hydrology of individual stream reaches (2003, pp. A-2, A-3).

Hager, et al. (2004) measured flows when possible during sampling events. The largest flows were observed during the March 15th and April 13th storm events. Stagnant or near stagnant conditions at some stations prevented flow measurement. Additional data on precipitation were retrieved from the California Irrigation Management Information System Watsonville West Station #177 and the Green Valley Station No. 111 (CIMIS, 2003), as well as from the National Climatic Data Center Watsonville Waterworks Station No. 049473 (NCDC, 2003) (Hager, et al., p. 35).

Spatial Data

Spatial data for this report include those required for: preparation of orientation maps; delineation of watershed boundaries; compilation of land use tables; and presentation of hydrologic and transportation networks. The County of Santa Cruz Planning Department provides many of the specific layers such as streams, roads, and municipal boundaries. Other layers are available as part of the Water Analysis Tool for Environmental Review (WATER) dataset, which is distributed via the web by the Central Coast Joint Data Committee. Manipulations of spatial data for delineating watershed boundaries and building land use tables are described below.

Watershed Boundaries and Planning Areas

Watershed boundary maps are used in this project to describe the condition of the watershed and to interpret the relative effects of land use on bacteria levels. Two maps developed by different methods were used, including one produced by the Watershed Institute (Hager, et al. 2004) and one produced by SH&G, et al., (2003). The Watershed Institute produced their map using a Digital Elevation Model

(DEM) based on USGS data, which they developed previously for the Central Coast Regional Water Quality Control Board. Multiple USGS 30-meter DEMs were mosaicked using Tarsier Software developed by Watson and Rahman (2003). This process is detailed in Newman et al. (2003). From the DEM, sub-watershed boundaries were determined for Watsonville Sloughs (Hager, et al., 2004, p. 16).

SH&G, et al. divided the entire watershed into morphologically similar subwatershed units based on topography, channel morphology, land use coverage, and watershed position. They used USGS topographic maps and aerial photography in conjunction with field reconnaissance to determine drainage boundaries (2003, p. A-2).

Land Use and Land Cover

Two approaches to land use/land cover were available for use in this analysis. Data from both of these methods are included in the discussion, since there are strengths of both and evaluating them provides a means of checking their relative accuracy.

SH&G, et al., used Santa Cruz County assessors parcel GIS database and aerial photographs to determine land use coverage (Ibid.). This coverage uses classifications of land use, including: agricultural, grazing, urban residential, commercial, industrial, rural residential, and undeveloped land.

Hager, et al. used multi-band imagery, 30-meter resolution Landsat Enhanced Thematic Mapper scenes from 1999 through 2002 to calculate land use/land cover percentages. The resulting classification is more descriptive of land cover than land use and includes classes such as: vineyard/berries, irrigated row crop, shrub, bare soil, water, urban, oak woodland/mixed forest. Details of the entire classification process, including verification techniques are given in Newman, et al., 2003. The construction of tables from the land use/land cover polygons is described in Appendix A.

Municipal Stormwater Management Areas

The Watershed Institute also prepared a map and accompanying data tables for portions of the watershed under stormwater general municipal permit requirements. Regional Board staff provided a pdf format file of the boundary of the census-based urbanized area under city and county stormwater authority. Watershed Institute staff digitized this map and combined it with a GIS vector layer of the Watsonville City boundary and the subwatershed boundary layer prepared earlier. Staff then created in ArcMap, the map, which includes the stormwater management area boundary, City of Watsonville boundary, County boundary, waterbodies, watershed and sub-watershed boundaries, and shaded relief.

3.3. Findings from Existing Bacteria Data

In this study, the primary use of bacteria data from previous investigations is to identify general levels of pathogens and locate potential hot spots. However, the strength of comparison among these data is limited due to different sampling techniques, sampling frequency, analysis, and rainfall patterns between the various years for which samples were taken (Hager, et al., 2004, p. 11).

Santa Cruz County Environmental Health Services' pathogen monitoring data are summarized in Figure 3-2. For screening purposes, Hager, et al. labeled as "hot spots" those sites with geometric means (for all samples from that site) greater than 400 MPN/100ml (p. 12). They also indicated what percentage of a location's samples exceeded 400 MPN/100ml—a violation of the Basin Plan water quality objective for REC-1. Both of these measures are indicated in Figure 3-2, along with the total number of samples (N) taken over the indicated time period (e.g., 1992, 1994-97). The site codes for sampling locations are included in Table 3-4. These data reveal hot spots in the area near the confluence of Harkins Slough and

Watsonville Slough and in the heavily urbanized areas near the west branch and main branch of Struve Slough.

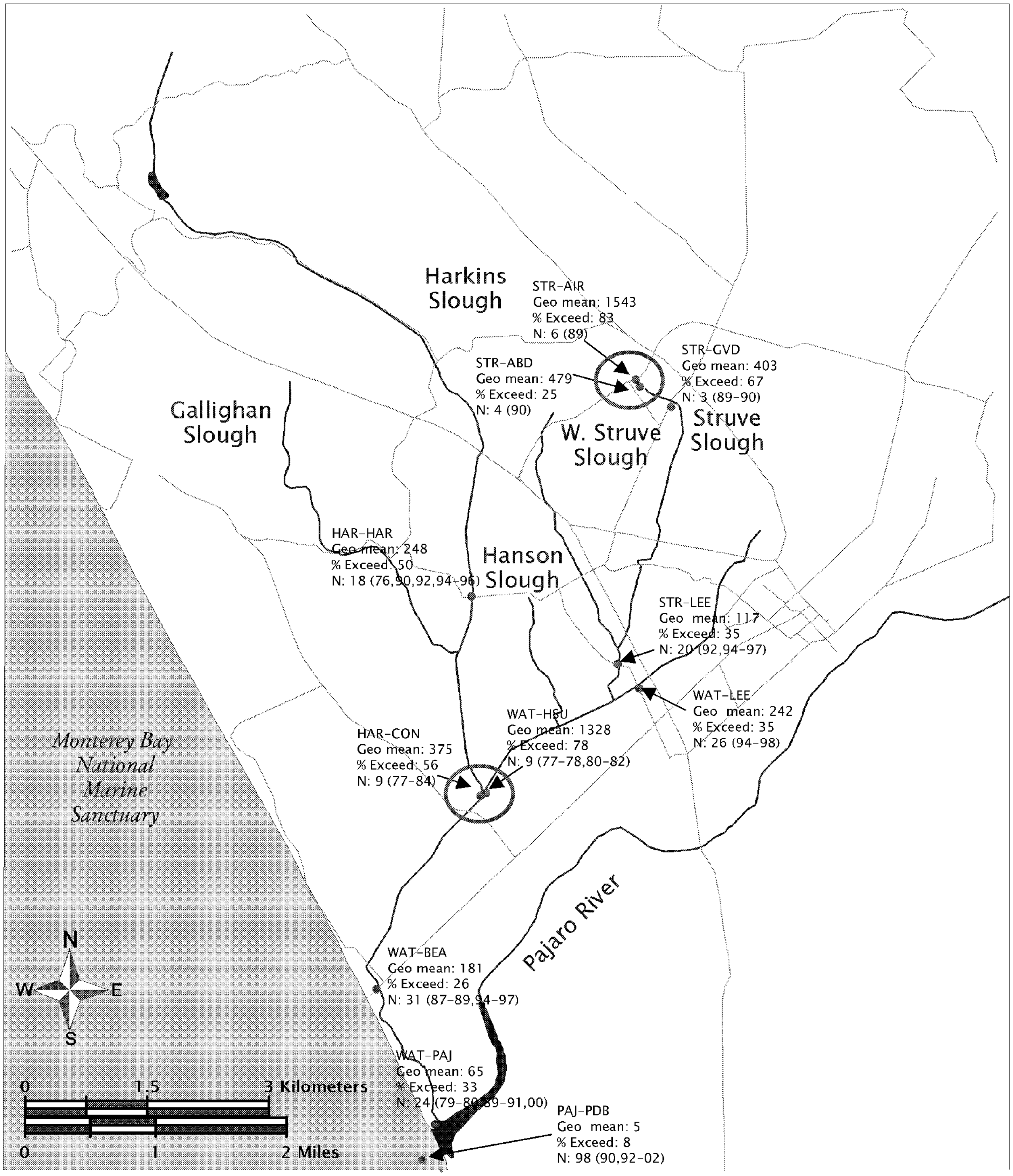


Figure 3-2 Santa Cruz County Environmental Health Services fecal coliform data showing geometric mean, percent exceedance of 400 MPN/100ml, and total number of samples (N) taken over time period in years.

Source: Figure 5.1, Hager, et al., 2004.

Table 3-4 Site code indices for previous studies.

Site Code	Location
WAT-PAJ	Watsonville Slough mouth at confluence with Pajaro River Lagoon
WAT-SHE	Watsonville Slough at Shell Rd.
WAT-AND	Watsonville Slough at San Andreas Rd.
WAT-HSD	Watsonville Slough downstream of Harkins Slough confluence
WAT-HAR	Watsonville Slough at Harkins Slough Rd.
WAT-HSU	Watsonville Slough upstream of Harkins Slough confluence
WAT-RWY	Watsonville Slough at railroad crossing
WAT-LEE	Watsonville Slough at Lee Rd.
WAT-WAL	Watsonville Slough at Walker Rd.
BEA-CON	Beach Road Ditch at confluence with Watsonville Slough
BEA-SHE	Beach Road Ditch at Shell Rd.
HAR-INF	Harkins Slough Diversion Project influent
HAR-CON	Harkins Slough confluence with Watsonville Slough
HAR-EFF	Harkins Slough Diversion Project effluent
HAR-HAR	Harkins Slough at Harkins Slough Rd.
GAL-LOW	Lower Gallighan Slough
GAL-HAR	Gallighan Slough near confluence with Harkins Slough
STR-LEE	Struve Slough at Lee Rd.
STR-HAR	Struve Slough at Harkins Slough Rd.

Source: Hager, et al., 2004.

Table 3-5 summarizes the Pajaro Valley Water Management Agency (PVWMA) data. The geometric means for fecal coliform samples at sites WAT-HSD and HAR-CON were greater than 400 MPN/100 ml. Also, all sites exceed the Basin Plan standard, since all have more than ten percent of samples greater than 400 MPN/100 ml. Though limited in geographic scope, these data generally support the hot spots hypothesis developed from Santa Cruz County Environmental Health Services data.

Table 3-5 Summary of fecal coliform data collected by PVWMA in 2002.

Site Code	(MPN/100 ml)					
	Jan	Feb	Mar	Apr	May	Geometric Mean
WAT-HSD	240	**1,300**	**800**	110	--	404
WAT-HSU	300	**800**	300	50	--	245
HAR-CON	**500**	**500**	**800**	<20	--	585
HAR-EFF	**1,100**	**1,400**	**2,200**	20	33	295

Bold text indicates exceedance of Basin Plan water quality criterion requiring <10% of samples exceeding 400 MPN/100 ml.
Source: Hager, et al., 2004, p. 86.

Regional Fecal Coliform Levels

This section compares fecal coliform levels between the Watsonville Sloughs system and the broader surrounding region in order to determine if potential problems in the Watsonville Sloughs system are unique, or simply typical of the region in general.

Data from the present study are compared with CCAMP data from 1998 to 2001 in Figure 3-3 and Table 3-6. A schematic describing the whisker plots is given in Figure 3-4. The sites in Figure 3-3 are organized according to approximate hydrologic and geographic provinces. Note that the CCAMP data were collected using a different sampling design, typically involving monthly sampling runs.

The Watsonville data are highly variable, but no more variable than sites throughout the region. The highest levels in the regional data set are from the intensely agricultural and urban areas between Castroville and the City of Salinas. The Watsonville data approach these levels, particularly at HAR-HAR and STR-CHE, but they do not exceed the regional maxima. The lowest levels in the regional data set are from the Salinas main stem and its largest tributaries in the Los Padres National Forest, such as Arroyo

Seco and the Nacimiento River. Some of the Watsonville sites approach these low levels, such as the tidal WAT-PAJ site, and at STR-LEE. Overall, the Watsonville data compare most closely with data from the nearby Pajaro River and its many tributaries. This is not surprising, given that the Pajaro watershed has a similar mix of land uses in its more coastal and northern parts (the southern and eastern parts are much drier grasslands and shrublands).

From this comparison, Hager, et al., concluded that the Watsonville Slough system is typical of many watersheds with mixed urban and agricultural uses and sluggish waters near the coast, and less intense uses in their headwaters.

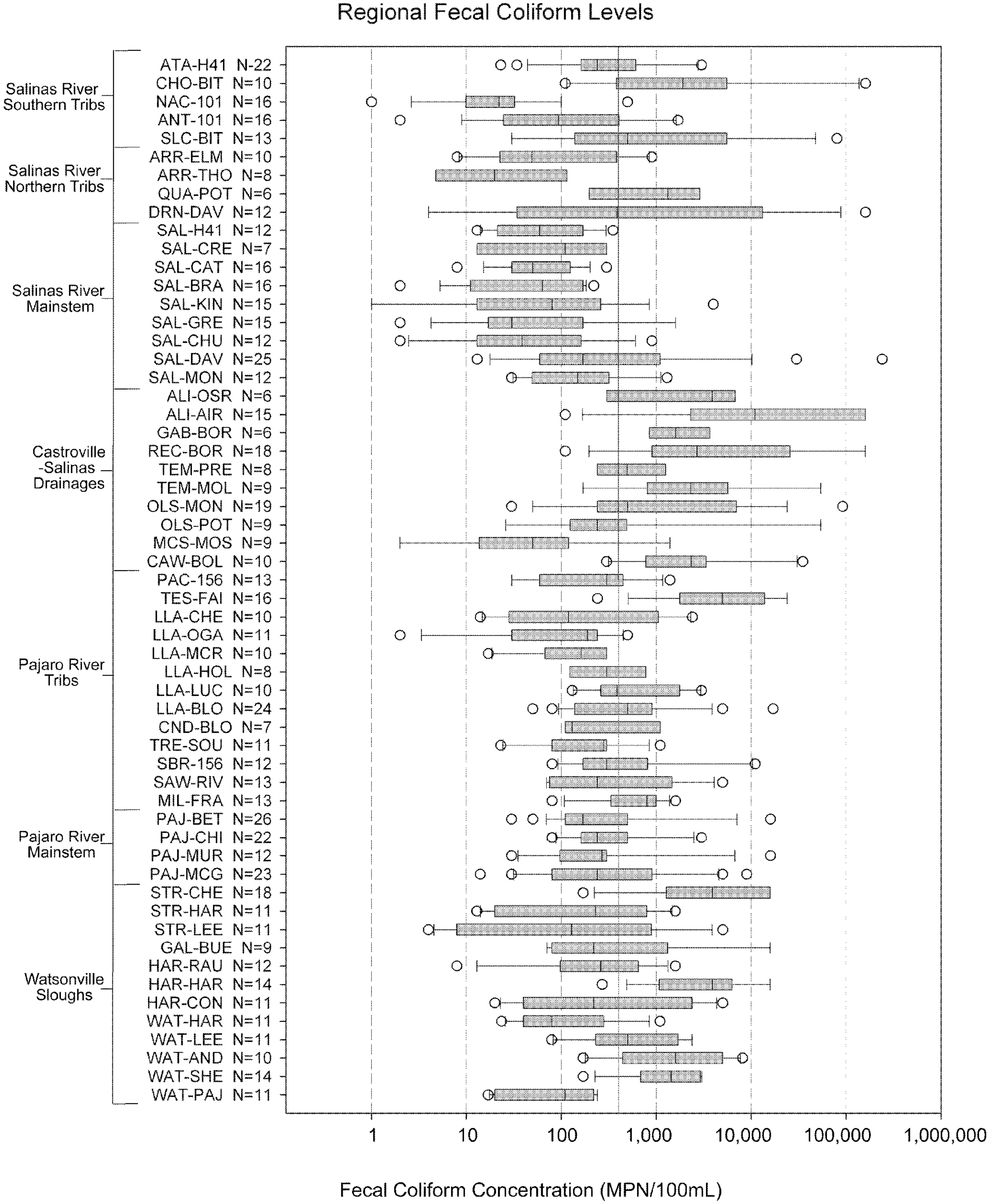


Figure 3-3: Regional fecal coliform levels for comparison with those in Watsonville Sloughs.
Source: Hager, et al., 2004 Figure 8.2.

Figure 3-4 Whisker plots explained

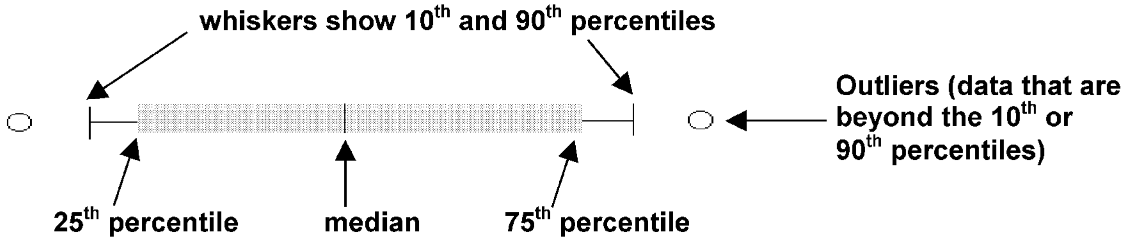


Table 3-6 CCoWS/CCAMP site codes for regional comparison.

CCoWS Site ID	CCAMP Site ID	Waterway	Site Description
PAJ-MCG	305THU	Pajaro River	McGowan Rd/Thurwachter Bridge
PAJ-MUR	305MUR	Pajaro River	Murphy's Creek Rd
PAJ-CHI	305CHI	Pajaro River	Chittenden Rd
PAJ-BET	305PAJ	Pajaro River	Betabel rd
MIL-FRA	305FRA	Miller Canal	Frazier Lake Rd
SAW-RIV	305COR	Salsipuedes Creek	Riverside Rd
SBR-156	305SAN	San Benito River	Hwy 156
TRE-SOU	305TRE	Tres Pinos Creek	Southside Rd
CND-BLO	305UVA	Carnadero Creek	Bloomfield Ave
LLA-BLO	305LLA	Llagas Creek	Bloomfield Ave
LLA-LUC	305LUC	Llagas Creek	Lucchessa Ave
LLA-HOL	305HOL	Llagas Creek	Holsclaw Rd
LLA-MCR	305MON	Llagas Creek	Monterey County Rd
LLA-OGA	305OAK	Llagas Creek	Oak Glen Ave
LLA-CHE	305CHE	Llagas Creek	Chesbro Reservoir
TES-FAI	305TES	Tequisquita Slough	Fairview Rd
PAC-156	305PAC	Pacheco Creek	Hwy 156
CAW-BOL	306CAR	Carneros Creek	Blohm Rd
MCS-MOS	306MOS	Moro Cojo Slough	Moss Landing Rd
OLS-POT	309POT	Old Salinas River	Potrero Rd (Tide Gates)
OLS-MON	309OLD	Old Salinas River	Monterey Dunes Colony Rd
TEM-MOL	309TDW	Tembladero Slough	Molera Rd
TEM-PRE	309TEM	Tembladero Slough	Preston Rd
REC-BOR	309ALD	Reclamation Ditch	Boronda Rd
GAB-BOR	309GAB	Gabilan Creek	Boronda Rd
ALI-AIR	309ALU	Alisal Creek	Airport Rd
ALI-OSR	309UAL	Alisal Creek	Old Stage Rd
SAL-MON	309SBR	Salinas River	Del Monte Rd
SAL-DAV	309DAV	Salinas River	Davis Rd
SAL-CHU	309SAC	Salinas River	Chualar River Rd
SALL-GRE	309GRN	Salinas River	Greenfield
SAL-KIN	309KNG	Salinas River	King City
SAL-BRA	309USA	Salinas River	Bradley Rd
SAL-CAT	309DSA	Salinas River	along Cattleman Rd
SAL-CRE	309PSO	Salinas River	Creston Rd
SAL-H41	309SAT	Salinas River	Hwy 41
DRN-DAV	309SDR	Storm Drain	300m upstream from Davis Rd
QUA-POT	309QUA	Quail Creek	Potter Rd
ARR-THO	309SET	Arroyo Seco River	Thorne Rd
ARR-ELM	309SEC	Arroyo Seco River	Elm Rd
SLC-BIT	309LOR	San Lorenzo Creek	along Bitterwater Rd
ANT-101	309SAN	San Antonio River	Hwy 101
NAC-101	309NAC	Nacimiento River	Hwy 101
CHO-BIT	317CHO	Cholame Creek	Bitterwater Rd
ATA-H41	309ATS	Atascadero Creek	Hwy 41

3.4. Findings from Grab Samples Collected for TMDL Development

Assuming that fecal coliform and *E. coli* are reliable indicators of pathogenic pollution, the levels of these organisms detected during this study indicate that Watsonville Sloughs has a pathogen problem throughout most of the system. The following discussion addresses where and to what degree the problem occurs. A subsequent section, *Source Analysis*, describes the results of sampling and analysis aimed at tracking the source of the problem. A more detailed discussion of the data is included in the report (Hager, et al., 2004) that staff used in preparing the following sections (Appendix A).

Areas in Exceedance of Basin Plan Objectives

The initial approach to determining the extent of pathogen problems in Watsonville Sloughs was to sample for total coliform, fecal coliform, and *E. coli* at multiple locations throughout the watershed during both the dry and rainy season. These two "exceedance monitoring" campaigns (summer and winter), each consisting of five sampling runs within a 30-day period, were designed specifically to determine where in the sloughs the Basin Plan's geometric mean objective of 200 MPN/ 100 ml was exceeded. After exceedance of the objective was confirmed, initial source tracking was undertaken with additional sampling (see Section 5 *Source Analysis*).

The results of the winter and summer exceedance monitoring for coliform showed that with the exception of WAT-PAJ, all 13 sites were in exceedance of the Basin Plan objective for fecal coliform during the winter, summer, or both. In most cases, *E. coli* concentrations alone caused exceedance of the fecal coliform objective (Hager, et al., p. 65). Although some sites were consistently higher than others, there was considerable variation in the data. For a given site, there was often a wide range in the level of fecal coliform detected. The ranges of the data in winter and summer were similar, ranging from nine to 2,784 MPN/100 ml *E. coli* in the winter, and 38 to 2,165 MPN/100 ml *E. coli* in summer (Ibid.).

Figure 3-5 and Figure 3-6 illustrate the time of sampling events relative to seasonal rainfall averages and to storms occurring over the sampling period. These figures serve to illustrate that although limited in number, sampling events generally captured representative wet and dry conditions.

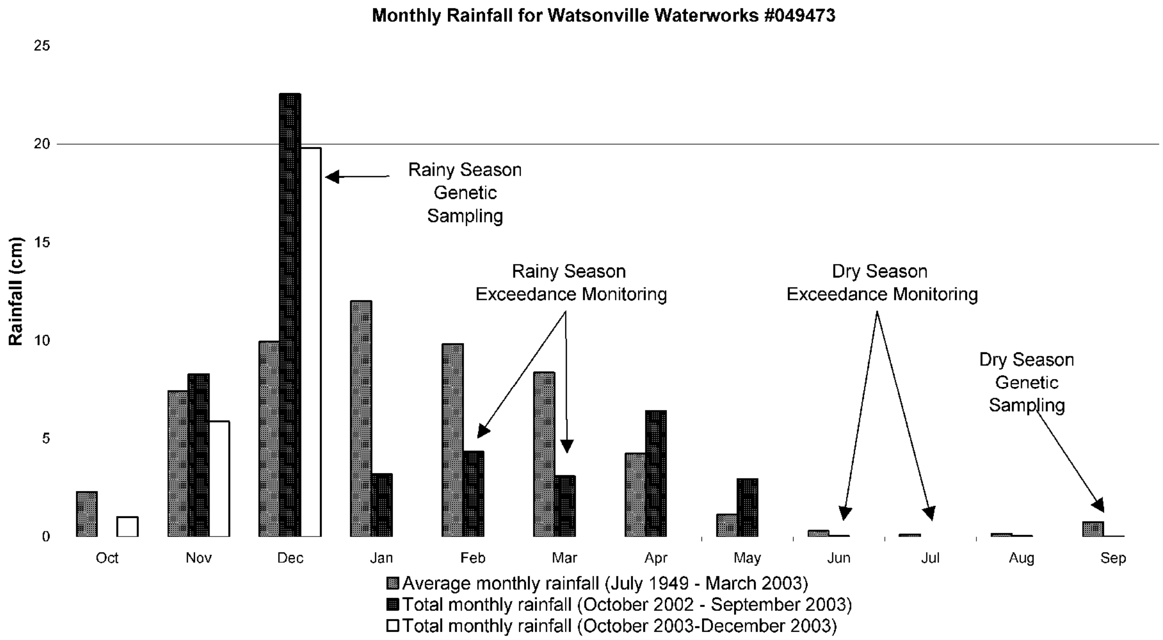


Figure 3-5 Monthly rainfall averages (1948-2003) and sampling event date.
Source: Hager, et al., 2004, Figure 7.1

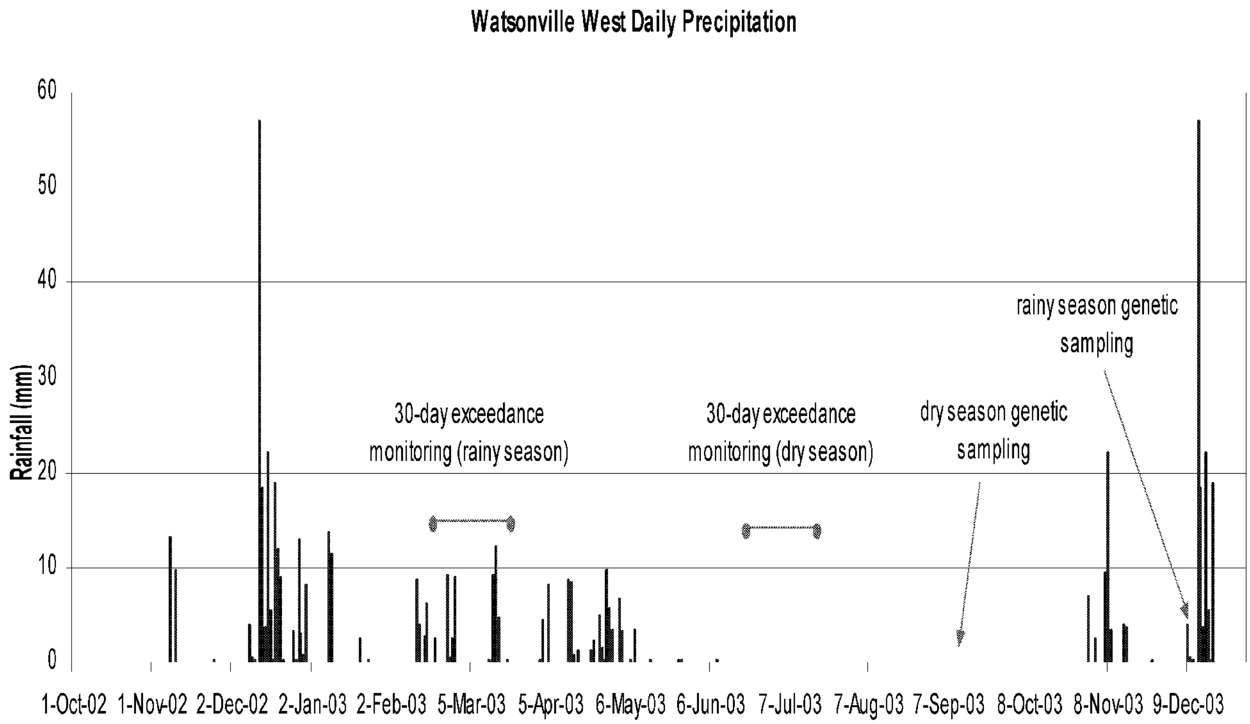


Figure 3-6 Daily precipitation data for CIMIS Watsonville West station. Data from December 20 to 30, 2003 not available.
Source: Hager, et al., 2004, Figure 7.2.

Winter Conditions

Winter exceedance monitoring results appear in Table 3-7 and Table 3-8. The data for *E. coli* reveal temporal variation within sites, as well as relative consistency among some sites Figure 3-7. For instance, *E. coli* values at STR-CHE ranged from 170 to 16,000 MPN/100 mL, but the geometric mean there was the highest of all sites.

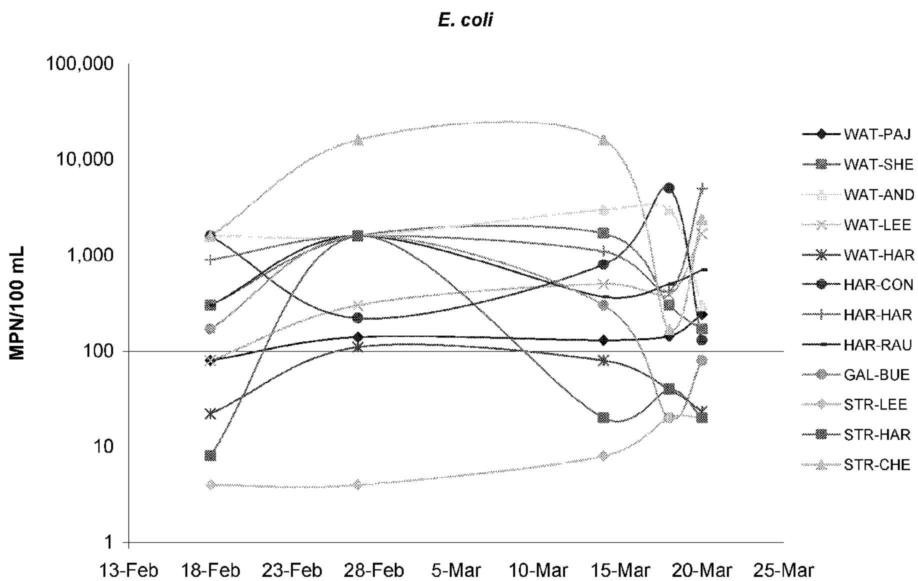


Figure 3-7 Temporal variability in winter *E. coli* data for Watsonville Sloughs.
Source: Hager et al., 2004.

On February 27th, a large increase was observed at most sites and the reasons for this are unknown. One hypothesis is that storm runoff transports bacteria from various sources leading to increases in the receiving waters. However, this hypothesis cannot be directly tested with this data set, since sampling events were not consistently timed to storm flow peaks. Another hypothesis, challenging to test even with a more robust data set, is that the observed responses are a function of environmental conditions that promote growth or decay of bacteria within the waterbodies.

Table 3-7 Watsonville Sloughs winter fecal coliform data.

Date	WAT-PAJ	WAT-SHE	WAT-AND	WAT-LEE	WAT-HAR	HAR-CON	HAR-HAR	HAR-RAN	GAL-BUE	HAN-HAR	STR-LEE	STR-HAR	STR-CHE
18-Feb-03	130	300	1,600	80	37	1,600	900	500	220	no flow	4	13	>=1,600
27-Feb-03	220	1,600	1,600	300	170	220	>=1,600	>=1,600	>=1,600	>=1,600	8	>=1,600	16,000
14-Mar-03	240	1,700	5,000	1,600	80	2,400	1,100	400	300	no flow	8	20	16,000
18-Mar-03	143	500	5,000	95	40	5,000	1,000	500	80	no flow	<20	40	170
20-Mar-03	240	170	300	1,700	23	130	5,000	700	80	no flow	20	20	2,400
Max	240	1,700	5,000	1,700	170	5,000	5,000	1,600	1,600	1,600	20	1,600	16,000
Min	130	170	300	80	23	130	900	400	80	1,600	4	13	170
Geometric mean	188	586	1,806	362	54	887	1,513	645	232	1,600	10	51	2,784
% Exceedance	0	60	80	40	0	60	100	80	20	100	0	20	80

Shaded regions show exceedance of Basin Plan fecal coliform REC-1 objective: geometric mean >200 MPN/100 mL, or more than 10% of samples exceeded 400 MPN/100 mL

Source: Hager, et al., 2004, p. 47.

Table 3-8 Watsonville Sloughs winter *E. coli* data.

Date	WAT-PAJ	WAT-SHE	WAT-AND	WAT-LEE	WAT-HAR	HAR-CON	HAR-HAR	HAR-RAN	GAL-BUE	HAN-HAR	STR-LEE	STR-HAR	STR-CHE
18-Feb-03	80	300	1,600	80	22	1,600	900	300	170	no flow	4	8	>=1,600
27-Feb-03	140	1,600	1,600	300	110	220	>=1600	>=1,600	>=1,600	>=1,600	4	1,600	16,000
14-Mar-03	130	1,700	3,000	500	80	800	1,100	367	300	no flow	8	20	16,000
18-Mar-03	143	300	3,000	390	40	5,000	420	500	20	no flow	<20	40	170
20-Mar-03	240	170	300	1,700	23	130	5,000	700	80	no flow	20	20	2,400
Max	240	1,700	3,000	1,700	110	5,000	5,000	1,600	1,600	1,600	20	1,600	16,000
Min	80	170	300	80	22	130	420	300	20	1,600	4	8	170
Geometric mean	138	529	1,472	380	45	712	1,272	573	167	1,600	9	46	2,784
% Exceedance	0	40	80	40	0	60	100	60	20	100	0	20	80

Shaded regions show E. coli alone causes exceedance of Basin Plan fecal coliform REC-1 objectives.

Source: Hager, et al., 2004, p. 47.

A map summarizing the fecal coliform data from the 30-day period of mid-February though mid-March is presented in Figure 3-8. Hot spots—sites with a geometric mean greater than 1,000 MPN/100 ml—are circled and include WAT-AND, HAR-HAR, and STR-CHE.

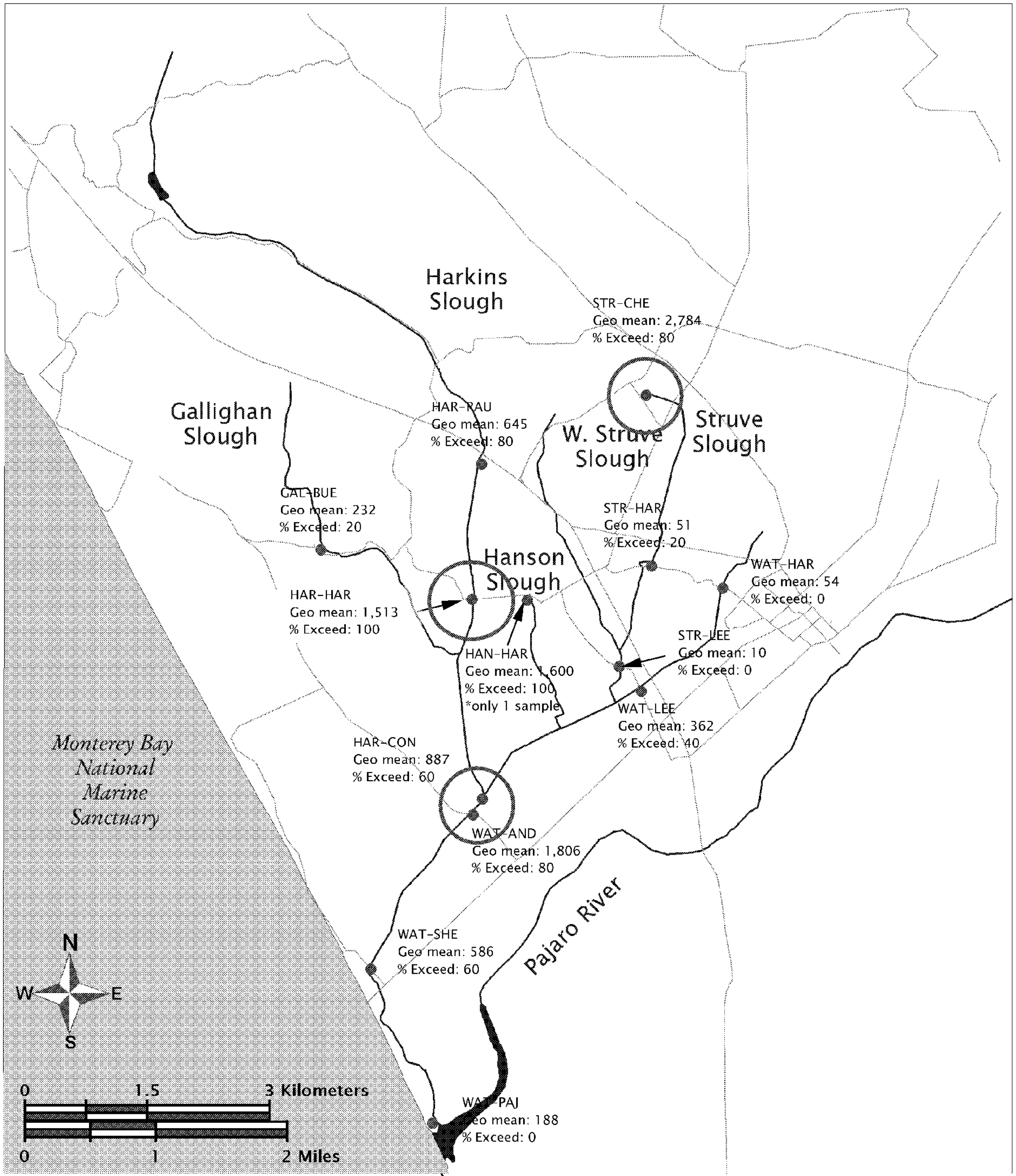


Figure 3-8 Winter fecal coliform data from February and March, 2003, showing geometric mean and percent exceedance of 400 MPN/100ml. Circles indicate hot spots with geometric means greater than 1,000 MPN/100ml.
Source: Hager, et al., 2004.

Summer Conditions

Summer exceedance monitoring results appear in Table 3-9 and Table 3-10. Hanson Slough was dry during the summer monitoring period so it does not appear in these tables. Eleven of the twelve primary monitoring sites were in exceedance of the fecal coliform objective for contact recreation with more than ten percent of the samples exceeding 400 MPN/100 ml. The only primary monitoring site that was not in exceedance of the Basin Plan for fecal coliform was WAT-PAJ.

Eight of the 12 primary sites were in exceedance of the fecal coliform geometric mean objective of 200 MPN/100 ml. Although WAT-AND and GAL-BUE were in exceedance only four samples were taken at WAT-AND due to a field error, and only three samples were taken at GAL-BUE, due to lack of water. Gallighan Slough at GAL-BUE did not flow during the last two weeks of the summer monitoring campaign.

A map summarizing the fecal coliform data is presented in Figure 3-10. Hot spots (geometric mean greater than 1,000 MPN/100 ml) are circled in and include WAT-SHE, HAR-HAR, and STR-CHE. Sites STR-CHE and HAR-HAR were also identified as hot spots during the winter exceedance monitoring.

Variation in coliform concentrations between sampling events for a given site was pronounced (Figure 3-9). For example, *E. coli* values at STR-CHE ranged from below 400 MPN/100 ml on one event to 8,135 MPN/100 ml on another. For any single sampling event, some sites had increases in concentrations from the previous run, while others had decreases.

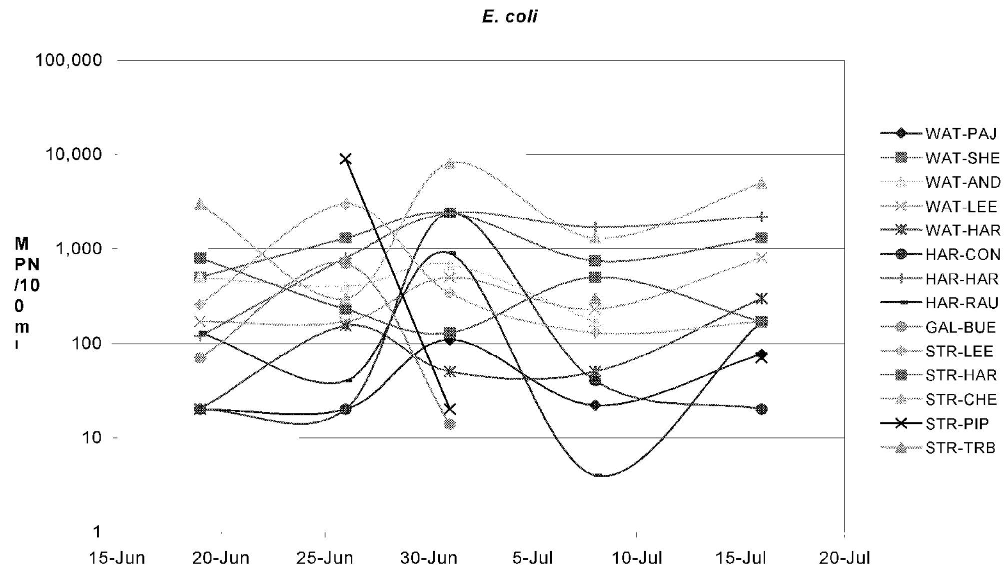


Figure 3-9 Temporal variation in summer *E. coli* data in Watsonville Sloughs.
Source: Hager, et al., 2004.

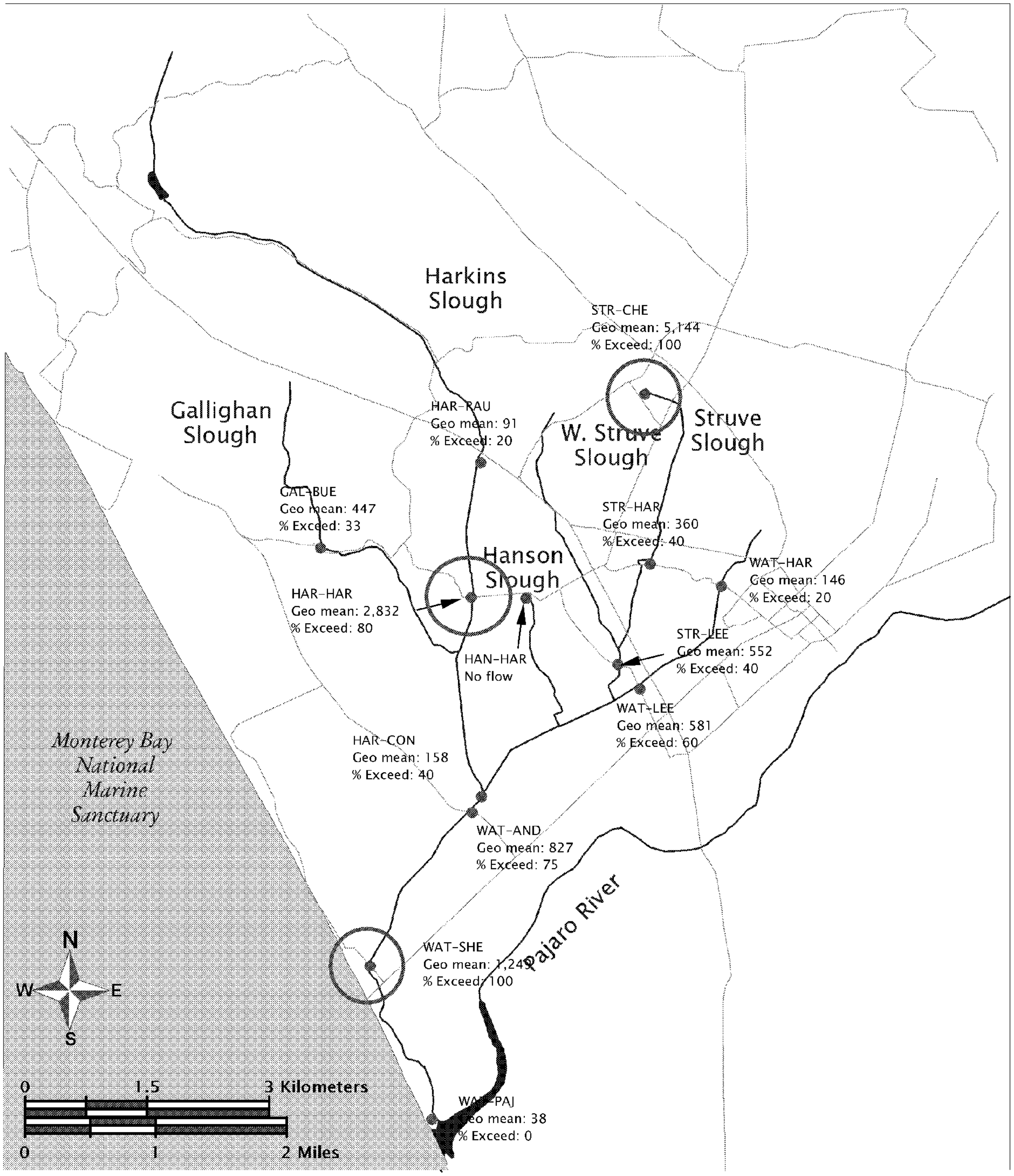


Figure 3-10 Summer fecal coliform data from June and July, 2003, showing geometric mean and percent exceedance of 400 MPN/100ml. Circles indicate hot spots with geometric means greater than 1,000 MPN/100ml.

Source: Hager, et al., 2004

Table 3-9 Watsonville Sloughs summer fecal coliform data.

Date	WAT-PAJ	WAT-SHE	WAT-AND	WAT-LEE	WAT-HAR	HAR-CON	HAR-HAR	HAR-RAN	GAL-BUE	STR-LEE	STR-HAR	STR-CHE	STR-PIP	STR-TRB
19-Jun-03	<20	800	500	300	80	40	270	130	70	1,367	800	3,000	x	x
26-Jun-03	20	1,300	8,150	2,400	1,10	1,300	5,000	40	16,000	5,000	230	5,000	>=16,000	x
01-Jul-03	110	3,000	675	500	50	2,400	3,000	900	80	340	300	16,000	<20	x
08-Jul-03	22	750	170	230	50	40	5,000	8	no flow	130	500	3,000	x	300
16-Jul-03	77	1,300	x	800	300	20	9,000	170	no flow	170	220	5,000	300	x
Max	110	3,000	8,150	2,400	1,10	2,400	9,000	900	16,000	5,000	800	16,000	16,000	300
Min	20	750	170	230	50	20	270	8	70	130	220	3,000	20	300
Geometric Mean	38	1,249	827	581	146	158	2,832	91	447	552	360	5,144	458	300
% Exceedance	0	100	75	60	20	40	80	20	33	40	40	100	33	0

x — No sample collected

Shaded regions show exceedance of Basin Plan fecal coliform REC-1 objective: geo mean >200 MPN/100 mL, or more than 10% of samples exceed 400MPN/100 mL

Table 3-10 Watsonville Sloughs summer *E. coli* data.

Date	WAT-PAJ	WAT-SHE	WAT-AND	WAT-LEE	WAT-HAR	HAR-CON	HAR-HAR	HAR-RAN	GAL-BUE	STR-LEE	STR-HAR	STR-CHE	STR-PIP	STR-TRB
19-Jun-03	<20	500	500	170	20	20	120	130	70	260	800	3,000	x	x
26-Jun-03	20	1,300	400	170	153	20	800	40	700	3,000	230	300	9,000	x
01-Jul-03	110	2,400	675	500	50	2,400	2,400	900	14	340	130	8,135	<20	x
08-Jul-03	22	750	170	230	50	40	1,700	4	no flow	130	500	1,300	x	300
16-Jul-03	77	1,300	x	800	300	20	2,200	170	no flow	170	170	5,000	70	x
Max	110	2,400	675	800	300	2,400	2,400	900	700	3,000	800	8,135	9,000	300
Min	20	500	170	170	20	20	120	4	14	130	130	300	20	300
Geometric Mean	38	1,087	389	305	74	60	971	80	88	358	289	2,165	233	300
% Exceedance	0	100	50	40	0	20	80	20	33	20	40	80	33	0

x — No sample collected

Shaded region show E. coli cause alone causes exceedance of Basin Plan fecal coliform REC-1 objective.

3.5. Findings on Impairment

Water quality objectives for protection of the REC1 beneficial use are routinely exceeded in several of the locations sampled in Watsonville Sloughs. REC2 water quality objectives allow for higher concentrations of fecal coliform bacteria and these objectives are more often met in the Sloughs. Staff is proposing de-designation of Watsonville Sloughs for the SHELL beneficial use. Therefore, staff attempted no determination of whether the Sloughs meet the SHELL water quality objectives in this analysis.

Water quality criteria for REC1 have been shown to be protective of human health-related beneficial uses. In this assessment, and in water quality attainment strategies that follow from its findings, staff assumes that these criteria are also protective of aquatic biota beneficial uses.

4. NUMERIC TARGETS

4.1. Targets

The numeric targets for Watsonville Sloughs, including Gallighan, Harkin, Hanson, and Struve Sloughs, will be based on Basin Plan water contact recreation standards, as they are the appropriate standard. (Table 4-1).

Table 4-1 Numeric targets for Watsonville Sloughs.

Fecal Coliform	
Geometric Mean	**Maximum**
200 MPN/100 ml[a]	400 MPN/100 ml[b]

a: Geometric mean of not less than five samples over a period of 30 days
b: Not more than 10% of total samples during a period of 30 days exceed
Source: Regional Water Quality Control Board, Basin Plan 1994.

5. Source Analysis

This section of the report evaluates additional bacteria data in an attempt to identify the sources of elevated levels of coliform bacteria in Watsonville Sloughs. The purpose of the Source Analysis is to identify sources and assist in allocating appropriate responsibility for actions needed to reduce these sources. This source analysis does this by:

- Examining initial source tracking efforts to isolate specific causes of high bacteria loads
- Looking for relationships between hydrologic conditions and bacteria levels
- Seeking connections between land use and bacteria counts, and
- Looking for correlation of land use and genetic source.

5.1. Initial Source Tracking

Following initial exceedance monitoring efforts and the discovery that Watsonville, Harkins, and Struve Sloughs each had at least one hotspot location (fecal coliform geometric means > 1,000 MPN/100 ml, (see Section 3)), Hager, et al. conducted additional monitoring to identify and isolate the source of bacteria affecting these sites.

Watsonville and Harkins Sloughs

The winter exceedance monitoring showed that fecal coliform levels were elevated in Watsonville Slough at WAT-AND, but were not as high at WAT-LEE (see Figure 3-1 for sampling locations). Since all sites on Harkins Slough were in exceedance of the objective, researchers hypothesized that high levels at WAT-AND were a result of inputs from Harkins Slough, which enters Watsonville Slough just above WAT-AND. They then conducted additional sampling in Harkins Slough to investigate the potential sources.

Researchers added four new sampling sites upstream of HAR-RAN and collected grab samples from these as well as HAR-RAN in an attempt to isolate locations in middle and upper Harkins Slough where very high levels and potential sources may exist. The results from two sampling events on April 17th and May 6th, 2003, included 20 analyses for total or fecal coliform, or *E. coli*, but failed to isolate a source or any apparent pattern of high concentrations (Hager, et al., pp. 49-53).

Struve Slough

To evaluate the high bacteria concentrations at STR-CHE, samples were initially collected at STR-CHE and at two other upstream locations: STR-CH1, located approximately 20 meters upstream of STR-CHE, and STR-AIR located upstream of STR-CH1 and immediately downstream of the Airport Boulevard crossing.

On April 17th, sites STR-CH1 and STR-AIR had lower fecal coliform levels than site STR-CHE. On May 6th this pattern was reversed for two of the sites; *E. coli* levels were slightly higher at STR-CH1 than at STR-CHE (laboratory results from May 6th at STR-AIR were discarded due to a possible laboratory error). During both sampling runs, bacteria concentrations for STR-CHE were lower in relation to the geometric mean observed during winter exceedance monitoring.

Since *E. coli* levels at STR-CHE remained high during the summer exceedance monitoring, additional efforts were made, in collaboration with the City of Watsonville, to determine the extent and source of the problem in the Cherry Blossom Drive area. Due to the small drainage area above this site, with only residential and a small municipal airport as the primary land uses, Hager, et al. hypothesized that human contamination was the source. The City of Watsonville manages the sewer lines of the neighboring houses of the Cherry Blossom/Loma Prieta Avenue area. City staff took a lead role in investigating the possible bacteria sources in upper Struve Slough.

On August 14th and 15th, 2003, the main sewer lines in the Cherry Blossom Drive area were dye tested. After several hours of close observation, City staff observed no traces of dye in the surrounding drainage area. The City then dye tested many of the neighboring houses to confirm their connection to the main sewer line. These dye tests, performed on August 26th and September 3rd, verified that all of the tested houses were connected to the main sewer lines.

Samples for fecal coliform and/or *E. coli* were collected in an effort to isolate the location of the source by detecting differences and increases between sites. Nine sites in the Cherry Blossom Drive area were sampled throughout August and early September, including six upstream, and two downstream of STR-CHE (Hager, et al., p. 58). Combining these results with those produced in the more limited effort in April and May, a total of 58 data points were generated in the investigation of this site on upper Struve Slough (see Appendix A for a more detailed presentation of results). Despite this focused sampling, the dye testing, and extensive reconnaissance of the area, the outcomes are inconclusive relative to the main objective of identifying the source of high bacteria counts observed during the exceedance monitoring phase. Nevertheless, Hager, et al., (p. 59) did draw the following conclusions from the investigation:

1) There <u>may</u> be a localized source of fecal coliform downstream of STR-CH3
2) Since fecal coliform levels at individual sites vary from very low to very high, there <u>may</u> either be:
   a) An intermittent source, or
   b) Variability in the factors that govern the processes linking the source to the sampling site (e.g. hydrology and connectivity) and/or factors that govern the growth and death of coliform bacteria such as temperature, light, and nutrients (Gerba, 2000)
3) It is no simple matter to isolate sources even at such small watershed scales using conventional methods such as multiple tube fermentation.

Conclusions on Initial Source Tracking

The primary conclusion to be drawn from these initial source tracking exercises is that the bacteria levels throughout Watsonville Sloughs are too variable to permit a simple source analysis based on limited sampling at multiple sites. No single site had much higher levels than other sites on either occasions, and data are too sparse to show a statistical difference between sites. Although there appeared to be differences between sites on a given day, these could be due to variation in the laboratory method. For instance, on April 17th values detected at two sites in upper Struve Slough were 654 and 300 MPN/100 ml using multiple tube fermentation. For this method, the 95% confidence limits for 300 MPN/100 ml range from 100 to 1,300 MPN/100 ml. Therefore, the difference between these two sites on that day could potentially be attributed to limitations of the analytical method rather than real differences in concentration (p. 50).

5.2. Findings from Genetic Analysis

Hager, et al., selected sampling sites WAT-SHE, HAR-HAR, and STR-CHE (See Figure 3-1 for sampling locations) for genetic source tracking based on the representativeness of surrounding land uses, and on high bacteria concentrations detected during the exceedance monitoring. These three sites had the highest geometric means for both fecal coliform and *E. coli* during the first phase of the study. Hager collected the first samples for genetic analysis on September 9, 2003 following the dry season exceedance monitoring, and the second samples on December 9, 2003, to capture wet season conditions. All samples were analyzed again for total coliform, fecal coliform, and *E. coli* to confirm that the hot spots identified earlier were persistent.

The genetic analysis was undertaken by the laboratory group led by Dr. Betty Olson at the University of California at Irvine. They analyzed 16 samples using the Toxin Gene Biomarker method. This method involves extracting DNA from *E. coli* colonies grown on agar plates from water in grab samples. The DNA is then analyzed for the presence or absence of toxin genes specific to a host animal. In this study, toxin genes searched for included those for rabbit, human, dog, bird, and cow. Sources other than these five may have been present in samples but would not have been detected using the Toxin Biomarker method. Other potential sources that may be present in Watsonville Sloughs include: cat, horse, sheep, goat, pig, rodents, and other small mammals such as fox, raccoon, skunk, and opossum. The Toxin Gene Biomarker method is described in detail in Appendix B.

Clear differences are apparent in the occurrence or frequency of the different biomarkers at most locations. Dog, bird, and cow are the most prevalent of the five animal sources in samples from Watsonville Sloughs (Table 5-1). Since the total number of *E. coli* increased between dry and wet seasons, the percent of a particular source in the population can change while the MPN value can stay the same (Figure 5-1).

E. coli from bird sources alone exceed 400 MPN/100ml in all samples. Thus, Basin Plan water quality objectives for contact recreational use of these waterbodies are not met due to natural sources. During the wet season, *E. coli* from dog and cow sources individually lead to an exceedance in all samples. *E. coli* from human sources exceeds 400 MPN/100ml only during the rainy season at STR-CHE (two of three replicate samples). *E. coli* from rabbit sources is well below 400 MPN/100 ml.

Table 5-1 Summary of biomarker PCR analysis (*E. coli* MPN/100ml).

PCR Summary	Rabbits		Humans		Dogs		Birds		Cows	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
STR-CHE A	0		9.3	93	43	1,500	2,400	4,600	0.36	4,600
STR-CHE B		0.3		430		2,400		4,600		4,600
STR-CHE C		0.74		430		2,400		2,400		2,400
Avg	**0**	**0**	**9**	**318**	**43**	**2,100**	**2,400**	**3,867**	**0**	**3,867**
WAT-SHE A	0	9.2	1.5	7.4	43	2,400	2,400	2,400	0.92	2,400
WAT-SHE B	0	7.4	0.74	7.4	43	1,500	2,400	1,100	0.36	11,000
WAT-SHE C	0	3.6	3	15	240	4,600	430	2,400	3.6	2,400
Avg	**0**	**7**	**2**	**10**	**109**	**2,833**	**1,743**	**1,967**	**2**	**5,267**
HAR-HAR A	0	74	23	200	430	1,100	930	1,100	3	11,000
HAR-HAR B	0	23	15	280	930	1,100	930	4,600	9.2	11,000
HAR-HAR C	0	3.6	3	280	2,400	1,100	2,400	1,100	3.6	4,600
Avg	**0**	**34**	**14**	**253**	**1,253**	**1,100**	**1,420**	**2,267**	**5**	**8,867**

Source: Hager, et al., 2004, Table 10.1.

Struve Slough near Cherry Blossom Drive

Although the watershed area above the STR-CHE sampling location is small, the major land uses are purely residential and urban, including a portion of the Watsonville Municipal Airport. The most prevalent detectable source of *E. coli* during the dry season was birds with an occurrence of 2,400 MPN/100ml in a single sample. Replicates were not taken during the dry season visit to this site. Approximately 98 percent of the five sources tested were attributed to bird sources, two percent to dog sources, and less than one percent to human and cow sources.

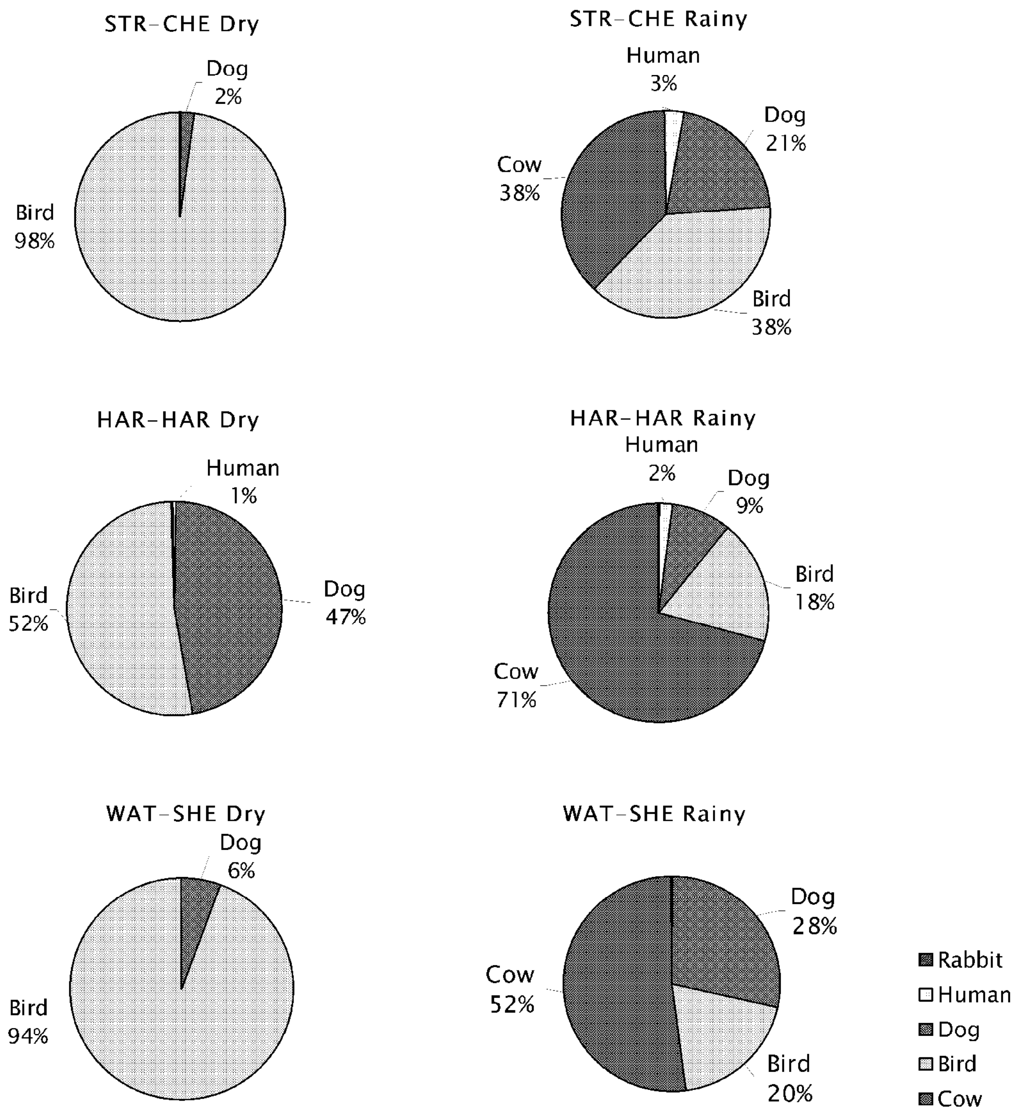


Figure 5-1 Percent composition of five *E. coli* biomarkers in water samples from three sites in Watsonville Sloughs. Note: other *E. coli* sources may have been present in sample; these charts only show percent composition for the five biomarkers that were screened.

During the rainy season, the most prevalent detectable sources of *E. coli* were cows and birds, both with an average concentration of 3,867 MPN/100ml. *E. coli* sources from dogs were also considerably high with an average occurrence of 2,100 MPN/100ml. *E. coli* attributed to humans increased considerably from the dry season to the wet season to an average 318 MPN/100ml for three replicate samples. Rabbit sources were less than 1 MPN/100ml for the rainy season. Thirty eight percent of the five sources tested were attributed to cows, 38 percent to bird, 21 percent to dog, and 3 percent to human (Figure 5-1).

Watsonville Slough at Shell Road

WAT-SHE has a large watershed area with multiple land uses/sources that are representative of the entire Watsonville Sloughs system (rural residential, urban, industrial, natural/recreation lands, grazing, and row crop agriculture). WAT-SHE is located at the bottom of the Watsonville Sloughs watershed and theoretically receives all inputs from upstream tributaries and all land uses under normal flow conditions.

At WAT-SHE the most prevalent detectable source of *E. coli* during the dry season was birds. The next most abundant detectable source of *E. coli* was dogs with an average of 109 MPN/100ml for three replicate samples. *E. coli* attributed to human and cow sources had occurrences less than 5 MPN/100ml for the dry season. About 94 percent of the five sources tested were attributed to bird sources and six percent to dog sources (Figure 5-1)

During the rainy season, the most prevalent detectable source of *E. coli* was cows (i.e. cattle) with an average of occurrence of 5,267 MPN/100ml. *E. coli* sources from dogs and birds were also considerably high. *E. coli* attributed to human and rabbit sources were less than 10 MPN/100ml for the rainy season. Cows accounted for 52 percent of the five sources tested, dog 28 percent, and birds 20 percent (Figure 5-1).

Harkins Slough at Harkins Slough Road

HAR-HAR is located in the middle portion of Harkins Slough and comprises almost half of the total area for the Watsonville Sloughs system. This site captures the effects of rural residential, grazing, and row cropland uses.

At HAR-HAR the most prevalent detectable source of *E. coli* during the dry season was birds. As was the case for WAT-SHE, the next most abundant detectable source of *E. coli* was dogs. *E. coli* attributed to human and cow sources had occurrences less than 25 MPN/100mL for the dry season. Approximately 52 percent of the five sources tested were attributed to birds sources, 47 percent to dog sources, one percent to human sources, and less than one percent to cow sources (Figure 5-1).

During the rainy season, the most prevalent detectable source of *E. coli* was cows with an average of occurrence of 8,867 MPN/100mL. *E. coli* sources from birds and dog were also considerably high with an average occurrence of 2,267 MPN/100ml for bird and 1,100 MPN/100ml for dog. *E. coli* attributed to humans increased to an average 253 MPN/100ml for three replicate samples, and rabbit sources increased to an average 34 MPN/100ml for the rainy season. 71 percent of the five sources tested were attributed to cows, 18% to bird, 9% to dog, and 2% to human (Figure 5-1).

Conclusions on Genetic Source Tracking

The major conclusions from the genetic source tracking are that coliform sources and magnitudes vary widely between seasons; that exceedances of Basin Plan objectives for REC-1 can be caused solely by natural sources (birds); and that runoff from land during the wet season plausibly explains the more diverse genetic sources of bacteria compared to those in the dry season.

5.3. Potential Influence of Circulation on Bacteria Concentrations

Hydrologic Modification

Human alteration of the hydrology of the Watsonville Sloughs has been significant. The overlay of drainage, transportation, and water transfer infrastructure on this lowland/wetland environment, combined with extensive groundwater pumping, has created areas plagued by persistent inundation and limited circulation. For example, significant and prolonged inundation occurred in the upper reaches of the slough system during the winter of 2001 — surface water persisted in upper Harkins and Struve Sloughs in mid June 2001. This occurred in spite of the fact that 2001 was a below average winter with respect to rainfall with just 40 cm of rainfall, as compared to the average of 60 cm (SH&G, et al., 2003, p. A-24). Rainstorms in December of 2003 produced flooding in lower Watsonville Slough and reverse flow toward tributary sloughs Harkins and Struve. Floodwaters inundated the lower Pajaro River and potentially contributed to flooding the lower Watsonville Sloughs. Floodwaters flowed up Watsonville Slough, around the pump station at the confluence of Watsonville and Harkins Sloughs and into Harkins. Also, floodwaters from middle Watsonville Slough overtopped the levee-banks and flowed across agricultural fields into Harkins Slough above the pump station (Hager, et al., 2004, p. 36).

Non-flood flow is generally sluggish in areas outside of Larkin Valley and the headwater of Struve Slough. Hager, et al. found limited measurable discharge throughout their sampling campaigns. But what they did find corresponds well with the SH&G, et al. findings on circulation (Table 5-2). Even in reaches with relatively high circulation ratings, typified by HAR-RAN and STR-CHE, flow rates were generally low and often too low to obtain an accurate measurement.

Table 5-2 Discharge measurements during exceedance monitoring campaign (cubic meters/second).

Date	GAL-BUE	HAN-HAR	HAR-RAN	STR-CHE	WAT-LEE
Circulation Rating	**High-Moderate**	**Low**	**High**	**High**	**Low**
18-Feb-03	0.004	no flow	-	0.001	0.052
27-Feb-03	0.016	0.003	0.103	0.004	0.113
13-Mar-03	0.006	x	0.019	x	x
14-Mar-03	0.015	no flow	0.019	0.001	0.011
15-Mar-03	0.066	0.010	1.432	0.064	0.197
18-Mar-03	x	no flow	0.009	0.003	0.055
20-Mar-03	0.010	no flow	0.021	0.001	0.043
13-Apr-03	0.018	0.004	0.037	0.045	0.291
13-Apr-03	0.038	0.003	0.030	0.014	0.142
19-Jun-03	0.001	no flow	-	0.006	0.002
26-Jun-03	0.000	no flow	-	-	0.001
01-Jul-03	0.001	no flow	-	0.002	0.003
08-Jul-03	no flow	no flow	-	0.003	0.004
13-Jul-03	no flow	no flow	-	0.001	x
16-Jul-03	no flow	no flow	-	0.001	0.002

\- Not enough flow for discharge measurement.
x Site not visited or no measurement taken.
Source: Derived from Hager, et al., 2004, p. 43, and SH&G, et al., 2003, Table A-2.

These observations of flood flows, persistent inundation, and poor circulation lead to the hypothesis that the lack of drainage in these areas results from the acceleration of land subsidence due to historic shallow groundwater removal and decomposition of organic soil, potentially exacerbated by the sustained weight of water atop these areas. "It is difficult to predict whether or not the land surface is now at steady state, or if subsidence may continue to increase during upcoming winters." (SH&G, et al., 2003, p. A-24).

Relating Circulation to Bacteria Levels

The significance of this alteration of hydraulic function to the delivery, transport, and reproduction of bacteria is a complex issue. Addressing the issue first requires a characterization of waterbody segments, or, reaches. SH&G, et al (2003) provide such a characterization—one describing the circulation rating (high, moderate, low, or stagnant), and the type of flow that dominates each reach (Figure 5-2):

1) *Perennial*: Flow all year with seasonal baseflow maximum occurring late winter/early spring; peak flows in winter rainfall
2) *Winter Inundation* (i.e., Seasonal Lake): Areas of open water during winter and spring
3) *Agricultural Drainage*: streams dominated by runoff from agricultural lands and tile drain/sump discharge; includes main agricultural ditches
4) *Intermittent*: Baseflow expended between late winter and fall, peak flows
5) *Ephemeral*: Only flows during winter rainfall events
6) *Urban Drainage*: Drains or watercourses dominated by urban runoff during rainfall events (2003, pp. A-2, A-3).

Staff attempted to associate available bacteria concentration data with this broad characterization of waterbody circulation to explore the possibility of a relationship between circulation and high bacteria counts (Table 5-3). It is apparent from this limited data set that no strong correlation exists. *E. coli* concentrations in exceedance of water quality objectives occur in waterbodies of all circulation ratings except moderate. Similarly, levels below the objective are found in waterbodies of all circulation ratings.

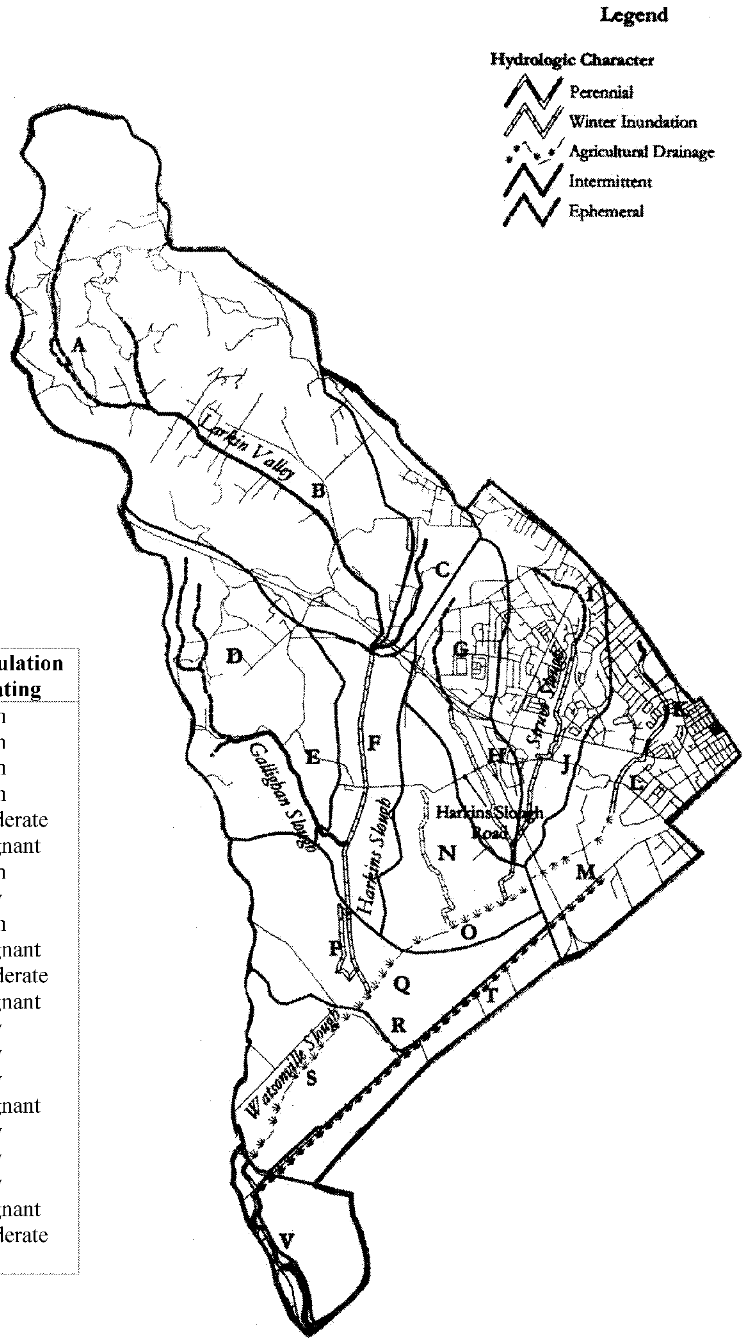
Table 5-3 Comparing *E. coli* concentrations with circulation ratings in Watsonville Sloughs (2003).

Reach ID	Waterbody	Circulation Rating	Winter *E. coli* Geo. Mean	Summer *E. coli* Geo. Mean	Closest Sampling Site
			(MPN/100ml)		
A	Upper Larkin Valley	High	-	-	*No match*
B	Lower Larkin Valley	High	**573**	80	HAR-RAN
C	Harkins Slough Trib	High	**573**	80	HAR-RAN
D	Upper Gallighan Slough	High	167	88	GAL-BUE
E	Lower Galligan Slough	Moderate	-	-	*No match*
F	Upper Harkins Slough	Stagnant	**1,272**	**971**	HAR-HAR
G	Upper W Branch Struve	High	-	-	*No match*
H	Lower W Branch Struve	Low	9	**358**	STR-LEE
I	Upper Struve Slough	High	**2,784**	**2,165**	STR-CHE
J	Lower Struve Slough	Stagnant	46	**289**	STR-HAR
K	Watsonville Slough Headwaters	Moderate	45	74	WAT-HAR
L	Watsonville Slough Marsh	Stagnant	45	74	WAT-HAR
M	Watsonville Slough N of Hwy 1	Low	**380**	**305**	WAT-LEE
N	Hanson Slough	Low	**1,600**	*NA*	HAN-HAR
O	Mid Watsonville Slough	Low	-	-	*No match*
P	Lower Harkins Slough	Stagnant	**712**	60	HAR-CON
Q	Mid Watsonville Slough	Low	**1,472**	**389**	WAT-AND
R	Beach Rd North Ditch	Low	-	-	*No match*
S	Lower Watsonville Slough	Low	**529**	**1,087**	WAT-SHE
T	Beach Rd South Ditch	Stagnant	-	-	*No match*
V	Watsonville Slough Estuary	Moderate	138	38	WAT-PAJ

See Figure 5-2 for location of waterbody reach location.
Bold text indicates *E. coli* fraction alone exceeds Basin Plan fecal coliform objective of geometric mean >200 MPN/100ml.
Source: Data from Hager, et al, pp. 47, 55; SH&G, et al., 2003, Table A-3.

Summary

From this analysis we conclude that any assumptions about a relationship between the occurrence of bacteria and circulation in this extensively modified system, is unsupportable with existing data. Stated another way, there is no evidence in this analysis that increasing circulation in the sloughs would result in lower concentrations of bacteria or permit the attainment of water quality objectives. Nevertheless, these results do not rule out the possibility that stagnant waterbodies capture, retain, and reproduce bacteria in a manner that explains high concentrations.



Reach ID	Waterbody	Circulation Rating
A	Upper Larkin Valley	High
B	Lower Larkin Valley	High
C	Harkins Slough Tributary	High
D	Upper Galligan Slough	High
E	Lower Galligan Slough	Moderate
F	Upper Harkins Slough	Stagnant
G	Upper W Branch Struve	High
H	Lower W Branch Struve	Low
I	Upper Struve Slough	High
J	Lower Struve Slough	Stagnant
K	Watsonville Slough Headwaters	Moderate
L	Watsonville Slough Marsh	Stagnant
M	Watsonville Slough N of Hwy 1	Low
N	Hanson Slough	Low
O	Mid Watsonville Slough	Low
P	Lower Harkins Slough	Stagnant
Q	Mid Watsonville Slough	Low
R	Beach Rd North Ditch	Low
S	Lower Watsonville Slough	Low
T	Beach Rd South Ditch	Stagnant
V	Watsonville Slough Estuary	Moderate

Figure 5-2 Stream reaches and circulation ratings in Watsonville Sloughs
Source: based on SH&G, et al., 2003.

Another important conclusion from this analysis of hydro-modification derives from the observation of a set of critical conditions, including:

- Limited to non-existent flow in many parts of the system throughout most of the year
- Reversal of flow during flood stage and the potential introduction of extra-basin source water (from the Pajaro River)
- Prolonged inundation and stagnation

The conclusion is that these conditions would seriously complicate any attempt to identify load-based limits (i.e., mass, or, numbers of organisms allowable over specified period of time) for bacteria. Partitioning flow in these waterbodies—the first step in converting concentrations to loads—would require far more intensive discharge and bacteria monitoring than has been conducted to date. Under these conditions the effort to develop load-based limits would not likely produce meaningful results. The alternative, to use concentrations in lieu of loads, is discussed in Section 8 TMDL Calculation and Allocations.

5.4. Potential Influence of Land Use on Bacteria Source

Land Use Distribution

Table 5-4 displays land uses throughout the Watsonville Sloughs watershed. Agriculture remains the largest land use despite continued development pressure on farmlands from population growth throughout the Monterey Bay Region. More than half of the row crop agriculture occurs in the Watsonville Slough subwatershed (Hager et al., 2004b).

Grazing and rural residential land uses share the rank of second most dominant land use throughout the watershed, with approximately 2,273 and 2,378 acres in each use, respectively. The great majority of these acres fall within the boundaries of the Larkin Valley, Harkins Slough, and Gallighan Slough subwatersheds (Table 5-4). However, 74 acres of grazing occur in the Middle Watsonville/Hanson subwatershed. Most of these acres drain directly to Hanson Slough. Both rural residential and grazing land uses are common sources of fecal coliform, which can originate from septic systems and manure, respectively.

Urban residential, commercial, and industrial uses are concentrated in Upper Watsonville and Struve Slough subwatersheds, though Harkins Slough has some urban uses where the City of Watsonville overlaps its subwatershed boundary. Upper Harkins Slough is largely undeveloped according to assessor's parcel data (Table 5-4).

Table 5-4 Land use by subwatershed in acres.

Subwatershed (From SH&G, et al., 2003)	**TOTAL AREA**	**Agricultural**	**Grazing**	**Urban Residential**	**Commercial**	**Rural Residential**	**Industrial**	**Undeveloped**
	Acres							
Upper Watsonville	**1,252**	313	0	626	313	0	0	0
Middle Watsonville/Hanson	**738**	664	74	0	0	0	0	0
Harkins/Watsonville Confluence	**978**	929	0	0	0	49	0	0
Lower Watsonville	**659**	560	0	0	0	0	0	99
Harkins Slough Tributary	**442**	0	0	0	0	309	88	44
Larkin Valley	**3,877**	78	1,939	0	0	1,551	0	310
Upper Harkins Slough	**627**	31	125	0	0	63	0	408
Gallighan	**1,353**	474	135	0	0	406	68	271
Struve Slough	**992**	99	0	446	446	0	0	0
West Branch Struve	**715**	143	0	107	250	0	72	143
Lower Beach Road	**343**	343	0	0	0	0	0	0
TOTAL	**11,976**	3,634	2,273	1,180	1,010	2,378	228	1,274
		30%	19%	10%	8%	20%	2%	11%

Acreage figures were back calculated from percentages and total area of subwatershed.
Source: SH&G, et al., 2003, Table A-2.

Comparing Exceedances with Land use Data

Examining the association of dominant land use in subwatersheds with exceedances of water quality objectives, it is evident that exceedances may occur in summer and/or winter in waterbodies regardless of dominant land use (Table 5-5). Stated another way: all land uses are associated with exceedances of water quality objectives.

Table 5-5 Dominant land uses surrounding locations and results of grab sampling for exceedance monitoring in Watsonville Sloughs, 2003.

Reach ID	Waterbody Reach	Subwatershed	Dominant Land Use (= or > 10% of Sub'shed)	Winter *E. coli* (Geometric Mean in MPN/100ml)	Summer *E. coli*	Closest Sampling Location
A	Upper Larkin Valley	Larkin Valley	-	-	-	*No match*
B	Lower Larkin Valley	Larkin Valley	Graz/RurRes	**573**	80	HAR-RAN
C	Harkins Slough Trib	Harkins Slough Trib	RurRes/Ind/Undev	**573**	80	HAR-RAN
D	Upper Galligan Slough	Gallighan Slough	Ag/RurRes/Undev/Graz	167	88	GAL-BUE
E	Lower Gallighan Slough	Gallighan Slough	-	-	-	*No match*
F	Upper Harkins Slough	Upper Harkins Slough	Undev/Graz/RurRes	**1,272**	**971**	HAR-HAR
G	Upper W Branch Struve	West Branch Struve	-	-	-	*No match*
H	Lower W Branch Struve	West Branch Struve	Com/Ag/Undev/Urb/Ind	9	**358**	STR-LEE
I	Upper Struve Slough	Struve Slough	Urb/Com/Ag	**2,784**	**2,165**	STR-CHE
J	Lower Struve Slough	Struve Slough	Urb/Com/Ag	46	**289**	STR-HAR
K	Watsonville Slough Headwaters	U. Watsonville Slough	Urb/Com/Ag	45	74	WAT-HAR
L	Watsonville Slough Marsh	U. Watsonville Slough	Urb/Com/Ag	45	74	WAT-HAR
M	Watsonville Slough N of Hwy 1	U. Watsonville Slough	Urb/Com/Ag	**380**	**305**	WAT-LEE
N	Hanson Slough	Mid Watsonville Slough	Ag/Graz	**1,600**	*NA*	HAN-HAR
O	Mid Watsonville Slough	Mid Watsonville Slough	-	-	-	*No match*
P	Lower Harkins Slough	Harkins/Watsonville Conflue.	Ag	**712**	60	HAR-CON
Q	Mid Watsonville Slough	Harkins/Watsonville Conflue.	Ag	**1,472**	**389**	WAT-AND
R	Beach Rd North Ditch	Harkins/Watsonville Conflue.	-	-	-	*No match*
S	Lower Watsonville Slough	Lower Watsonville Slough	Ag/Undev	**529**	**1,087**	WAT-SHE
T	Beach Rd South Ditch	Upper Beach Road	-	-	-	*No match*
V	Watsonville Slough Estuary	Lower Beach Road	Ag	138	38	WAT-PAJ

See Figure 5-2 for location of waterbody reach location.
Bold text indicates *E. coli* alone exceeds Basin Plan objective of geometric mean >200 MPN/100ml.
Source: Data from Hager, et al, pp. 47, 55; SH&G, et al., 2003, Table A-3.

Comparing Genetic Data with Land Uses

Similar to the results from the comparison of exceedances to land uses, a parallel examination of genetic source data relative to land use at the subwatershed scale yields inconclusive results. The expected correlation between grazing land use and the presence of cow *E. coli* is confirmed in Upper Harkins Slough, but not in Struve or Lower Watsonville (Table 5-6). Human coliform might be expected in rural residential land uses, since septic sewage disposal is a common practice and often these systems operate inefficiently. But, human biomarkers are seen where rural residential uses exist and where they do not exist.

One important feature of this comparison is the consistent depression of the bird component with wet conditions. It is reasonable to infer, as in the case of Struve Slough, that winter runoff introduced additional source material, reducing the proportion of bird bacteria from 98 to 38 percent. While this confirms an influence from terrestrial sources, these data do not offer evidence that the influence is land use driven. Stated another way, terrestrial sources (dog, cow, human) are not well correlated with available land use data.

Table 5-6 Land uses surrounding sampling locations for genetic source tracking and results of genetic analysis for wet and dry seasons in Watsonville Sloughs, 2003.

Land use (Percent of subwatershed)		Rabbits		Humans		Dogs		Birds		Cows	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Struve Slough (STR-CHE)		Percent of Sample									
Urban	45%	0	0	0	3	2	21	98	38	0	38
Commercial	45%										
Agricultural	10%										
Lower Watsonville Slough (WAT-SHE)											
Agricultural	85%	0	0	0	0	6	28	94	20	0	52
Undeveloped	15%										
Upper Harkins Slough (HAR-HAR)											
Undeveloped	65%	0	0	1	2	47	9	52	18	0	71
Grazing	20%										
Rural Residential	10%										
Agricultural	5%										

Source: Hager, et al., 2004, and SH&G, et al., 2003.

Land Uses Subject to Discharge Permits

The Central Coast Regional Water Quality Control Board has issued wastewater and stormwater discharge permits for several facilities, the City of Watsonville, and Santa Cruz County (Table 5-7). These permits are not for discharges containing bacteria or pathogens. Two of the facilities are permitted for discharge of treated septic system effluent to leachfields and/or ponds that percolate to groundwater; another facility discharges cooling system condensate directly to Watsonville Slough. The City of Watsonville and Santa Cruz County are enrolled under the General Permit for the Discharge of Stormwater from Small Municipal Stormwater Separate Storm Sewer Systems. Both the City and the County have areas within their permit coverage areas that are in the Watsonville Sloughs Watershed. Seven other facilities are enrolled under the general industrial stormwater permit.

The General Permit for the Discharge of Stormwater is a type of federal permit known as National Pollution Discharge Elimination Permits (NPDES), which require the dischargers to develop and implement a Storm Water Management Plan/Program with the goal of reducing the discharge of pollutants to the maximum extent practicable (MEP). MEP is the performance standard specified in Section 402(p) of the Clean Water Act. The management programs specify what best management practices (BMPs) will be used to address certain program areas. The program areas include public education and outreach; illicit discharge detection and elimination; construction and post-construction; and good housekeeping for municipal operations.

Facilities

None of the facilities are expected to be sources of pathogens entering the Watsonville Slough System. However, the two facilities with septic leachfields and ponds pose a potential risk in the event that their effluent stream is diverted to surface waters. Recent history at one of these facilities, described below, demonstrates the importance of maintaining the performance standards established in the permit.

In November 1994 septic tank effluent from the Buena Vista Migrant Labor Camp entered a culvert leading to Galligan Slough, but there was no confirmation of the amount, if any, that entered the Slough (Pohle, 1994). In late February 1998, for four days, pond failure associated with heavy rains resulted in approximately one million gallons of treated wastewater being discharged to Galligan Slough. Sampling conducted by the County prior to discharging the contents of the failing pond into the Slough to facilitate emergency repairs, showed *E. coli* in the discharge and in Gallighan Slough at concentrations of 17 and 140 MPN/100 ml, respectively. These data indicated no significant difference between the contents of the pond and the waters of the Slough relative to *E. coli* (Peterson, 1998). During the late 1990s, the facility occasionally exceeded permitted flow limits due to groundwater infiltration from heavy rains (Pohle, 1998; Fantham, 1997). As with most pond-based systems, the risk of upset at this facility exists and must be reduced or eliminated through management activities and improvements. The County Housing Authority proposed to complete operational improvements at the facility in July 2004 (Hoge, 2003).

The remaining permitted facilities are not expected to contribute pathogens to the surface waters in Watsonville Slough.

Table 5-7 Facilities and entities under permit from the Regional Water Quality Control Board in the Watsonville Slough watershed.

	Operation	Permit	Type of Discharge	Discharge Location
Facilities				
Apple Growers Ice & Cold Storage 850 West Beach St.	Cold storage for fresh, raw produce (mostly fruit).	General NPDES for Discharges with Low Threat to Water Quality	Discharge of condensate from cooling facilities and wash water Maximum: 42,000 GPD	Watsonville Slough approximately ½ mile upstream of WAT-LEE
Buena Vista Migrant Labor Camp 113 Tierra Alta Drive	Housing for farmworkers.	Waste Discharge Requirements	Discharge of sewage to onsite septic tank, percolation/evaporation ponds and leachfields. Maximum: 56,000 GPD	To groundwater adjacent to Harkins and Gallighan Sloughs downstream of GAL-BUE
Santa Cruz County Medium Security Jail,	96-bed medium security jail.	General Waste Discharge Requirements for Discharges to Land by Small Domestic Wastewater Treatment Systems.	Discharge of sewage to septic tanks and leachfields. Average: 9,600 GPD	To groundwater adjacent to Gallighan Slough, immediately east of ponds for labor camp and downstream of GAL-BUE.
Stormwater Entities				
City of Watsonville	Municipal separate storm sewer system (MS4)	Municipal Stormwater NPDES	Stormwater	
Santa Cruz County	MS4	Municipal Stormwater NPDES	Stormwater	
Various (7)	Landfills, airport, auto wreckers, food preparation, energy generation	Industrial Stormwater NPDES	Stormwater	Various, including: Gallighan, Harkins, Watsonville, and Struve Sloughs
California Department of Transportation	Highway 1		Stormwater	

Municipalities

Twenty six percent of the entire Watsonville Sloughs watershed is within stormwater management areas under County or City jurisdiction (Table 5-8). The great majority of this area is in urbanized portions of Watsonville and Struve Sloughs, where a combined estimated 2,696 acres, or 36% and 80%, respectively, are subject to the general permit for the discharge of stormwater (Figure 5-3). The Watsonville Airport, operated by the City of Watsonville, is also subject to a general industrial stormwater permit.

Stormwater runoff entraining potentially pathogenic material (e.g., organic debris, animal feces) is routed from land to adjacent waterbodies through stormdrains and related conveyances managed by the City and County. The County and the City both recently enrolled under the general municipal stormwater permit (2004) and are required to implement programs and practices to control polluted stormwater runoff.

Table 5-8 Municipal stormwater management area by subwatershed.

	Watershed Area	Municipal Stormwater Management Area		
Subwatershed	**Acres**		Percent of Total	Percent of Subwatershed
Watsonville	**3,493**	1,263	10%	36%
Harkins	**5,282**	534	4%	10%
Gallighan	**1,452**	0	0%	0%
Hanson	**399**	0	0%	0%
Struve	**1,798**	1,433	12%	80%
Total	**12,423**	**3,230**	**26%**	

The above analysis of land use influence on bacteria concentrations in the Watsonville Sloughs indicates that urban land uses are commonly associated with concentrations of *E. coli* in excess of water quality objectives. Furthermore, the analysis of genetic sources relative to land uses (Table 5-6) reveals that urban uses are implicated as sources of controllable fecal material from dogs and humans.

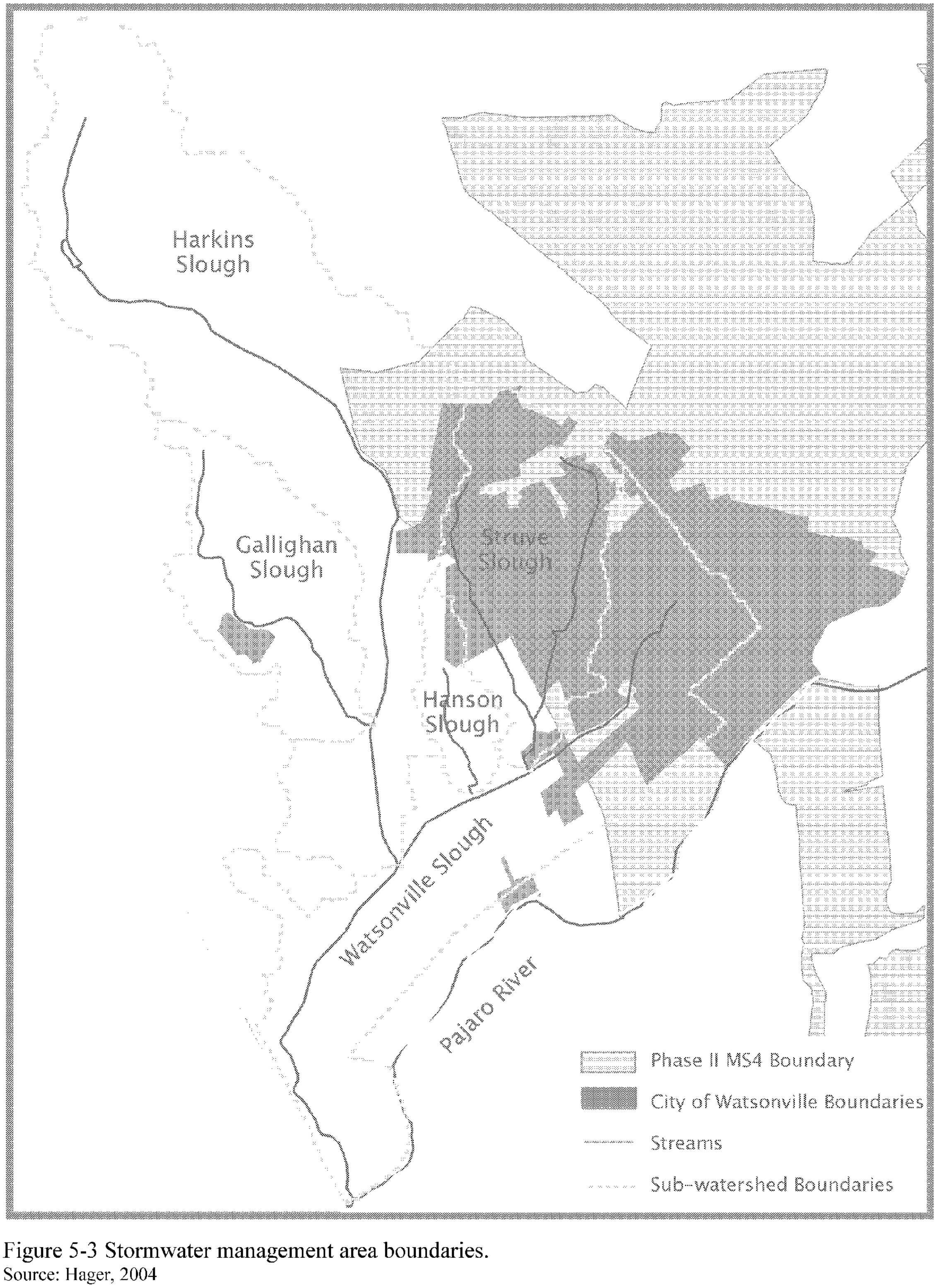


Figure 5-3 Stormwater management area boundaries.
Source: Hager, 2004

5.5. Source Analysis Conclusions

The objectives of this source analysis were only partly achieved and substantially more research is needed to definitively isolate sources of pathogens entering Watsonville Slough. The work to date supports the conclusion that several factors potentially explain high concentrations of bacteria. The impairment for pathogens may result from:

- Discrete, possibly intermittent sources (e.g. upper Struve Slough)
- Uncontrollable bird sources alone in the summer and winter
- Controllable dog and cow sources alone in the winter
- Human sources alone in at least one location (STR-CHE)
- Hydromodification resulting in poor circulation that may promote the capture, retention and reproduction of bacteria (areas throughout Harkins, Struve and Watsonville Sloughs)
- Any of the dominant land uses in the watershed
- Terrestrial inputs in the winter and natural sources (birds) alone in the winter

Bacteria contamination is not currently, nor is it expected to become a problem at existing permitted facilities. However, the permitted activity of stormwater management represents a source control opportunity, given the genetic analysis finding that terrestrial sources (e.g., cow, dog) are delivered to the waterbodies in winter runoff.

Another significant finding of the source analysis determines the subsequent approach to establishing TMDL allocations: load-based limits for bacteria (i.e., mass, or, numbers of organisms allowable over specified period of time) are not practical to establish in this system due to extensive hydromodification. In lieu of loads, concentration-based limits and allocations will be used in this TMDL.

Additionally, because of the potential for regrowth and die-off of bacteria in these waterbodies, definition and control of bacteria levels on a mass basis is impractical.

6. Critical Conditions and Seasonal Variation

This section considers factors affecting impairment of Watsonville Sloughs by pathogens (critical conditions), and whether seasonal variation in conditions there affect the impairment. The discussion is taken from Hager, et al. (2004, pp. 74, 75).

6.1. Critical Conditions

The critical conditions (Moe, 2002) or requirements for impairment by waterborne pathogenic organisms to occur, include:

1) Source (e.g. human waste)
2) Transmission through water (e.g. streamflow)
3) Survival and possibly growth of the infectious agent
4) Infectious dose (i.e. virulence)
5) Host susceptibility.

In the present study, transmission is assured by streamflow and stormwater runoff. We exclude issues of dose and susceptibility from our discussion. Thus, the conditions that are necessary for pathogen impairment in Watsonville Sloughs *may* include one or more of the following:

- Significant sources of human fecal matter
  - Despite lower indicator levels than for other biomarkers, human fecal matter is the most commonly cited source of waterborne infection (Moe, 2002)
- Significant sources of cow fecal matter
  - High indicator levels were measured, and cow fecal matter is known to contain the pathogenic *E. coli* strain O157:H7 (Rosen, 2000)
- Significant sources of dog fecal matter
  - Less likely, given lower indicator levels, and infrequently cited infection risk (Rosen, 2000)
- Significant sources of bird fecal matter
  - Unlikely. Although there were high indicator levels, bird feces is less commonly cited as a source of infection (Rusin et al., 2000)
- Growth-promoting waterbody conditions (see Gerba, 2000)
  - Sluggish, relatively deep water
  - High nutrient levels
  - High turbidity / suspended sediments (low light)
  - Warm temperatures
  - Few predators (invertebrates etc)

6.2. Seasonal Variation

The exceedance data and the genetic data differ with respect to indications of seasonal variation. Based on the exceedance monitoring data, there is no clear pattern of seasonal variation. Between summer and winter sampling periods, several sites increased and several decreased in fecal coliform levels – and these differences did not follow any clear spatial pattern. Looking at the *E. coli* data, there is a slight suggestion that levels were lower in winter at urban sites, and higher at other sites. However, two sites contradict this apparent trend (WAT-SHE and STR-CHE).

The genetic data follow a clearer temporal pattern. Mean biomarker MPNs increased from summer to winter in almost all cases. Based on these data, a preliminary conclusion may be reached that impairment is more likely during winter. The highest indications of human and cow fecal matter were obtained from the winter genetic samples. The processes leading to these observations may include entrainment of transient human waste, cattle waste, and inadequately composted manure within surface runoff; as well as entrainment of sewer or septic system leakage in surface and shallow sub-surface runoff.

The broader conclusion, however, is that coliform data exhibit so much spatial, temporal, and genetic variability that further study would be required to explain it. This is despite having results from several previous studies, and the endeavors of the present study, which involved 21 sampling sites; 163 exceedance samples and 32 exploratory samples analyzed for fecal coliform and *E. coli* MPN; and 18 genetic samples analyzed for five biomarkers each.

Conclusion

Though several conditions potentially account for the documented impairment, no critical conditions were confirmed, so load allocations and numeric targets were not adjusted. While the genetic analysis supports a preliminary conclusion that impairment is more likely during winter, exceedance data provide no clear pattern of seasonal variation. Therefore, load allocations and numeric targets were not adjusted for seasonal variation and the numeric targets in Table 4-1 will be applicable during periods of wet and dry weather.

7. LINKAGE ANALYSIS

The basic goal of this section is to clearly describe the process for establishing a linkage between pollutant loads and water quality for identifying the loading capacity that results in the instream numeric target. For this TMDL, this connection is established because the numeric targets are the TMDL. The numeric targets are protective of all the beneficial uses.

8. TMDL CALCULATION AND ALLOCATIONS

A TMDL is the loading capacity of a pollutant that a water body can accept while protecting beneficial uses. Usually, TMDLs are expressed as loads (mass of pollutant calculated from concentration multiplied by the volumetric flow rate), but in the case of pathogens, it is more logical for the TMDL to be based only on concentration. TMDLs can be expressed in terms of either mass per time, toxicity or other appropriate measure [40 CFR §130.2(I)]. A concentration based TMDL makes more sense in this situation because the public health risks associated with recreating in contaminated waters scales with organism concentration, and pathogens are not readily controlled on a mass basis. Therefore, we are establishing a concentration-based TMDL for pathogens in Watsonville Sloughs. The TMDL is the same set of concentrations as were proposed in the numeric targets section (Table 8-1).

Table 8-1 TMDL for Watsonville Sloughs

Fecal Coliform	
Geometric Mean	**Maximum**
200 MPN/100 ml[a]	400 MPN/100 ml[b]

a: Geometric mean of not less than five samples over a period of 30 days
b: Not more than 10% of total samples during a period of 30 days exceed

8.1. Proposed Load Allocations

The load allocations for all non-natural (controllable) sources will be equal to the TMDL concentration. These sources shall not discharge or release a "load" of bacteria that will increase the load above the assimilative capacity of the water body. All areas of the tributaries and sloughs will be held to these load allocations. Should all control measures be in place and fecal coliform levels remain high, investigation will take place to determine if the high level of fecal coliform is due to natural sources.

8.2. Margin of Safety

The margin of safety is a required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving water (CWA 303(d)(1)(C)). For pathogens in Watsonville Sloughs, a margin of safety has been established implicitly through the use of protective numeric targets, which are in this case the water quality objectives for the beneficial uses of the Sloughs.

The pathogen TMDL for Watsonville Sloughs is the water quality objective for REC-1. The Central Coast Region Water Quality Control Plan states that, "Controllable water quality shall conform to the water quality objectives... When other conditions cause degradation of water quality beyond the levels or limits established as water quality objectives, controllable conditions shall not cause further degradation of water quality." (CCRWQCB, p. III-2). Because the allocation for controllable sources is set at the water quality objective, if achieved these allocations will by definition achieve the water quality objectives. Thus, in this TMDL there is no uncertainty relative to the effect of loads from controlled sources on water quality.

However, in certain locations there is a distinct possibility that non-controllable, or, natural sources will themselves occur at levels exceeding water quality objectives. And while it is controllable water quality conditions ("actions or circumstances resulting from man's activities," (CCRWQCB, Basin Plan, p. III-2)) that must conform to water quality objectives, receiving water quality will contain discharge from both controllable and natural sources.

The ability to differentiate the controlled from the natural sources is the chief uncertainty in this TMDL. Monitoring of both discharges to the Sloughs, and Slough water itself, will indicate whether the allocations from controllable sources are met, thereby minimizing any uncertainty about the impacts of loads on the water quality.

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Appendix A: Watsonville Sloughs Pathogen Problems and Sources.

Appendix B: Genetic Source Identification Report.